# A STUDY OF THE SOILS DERIVED FROM SERPENTINITE AND ASSOCIATED ROCKS IN MARYLAND

by

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ABSTRACT

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Approximately 25,000 acres have been mapped as serpentinite-derived soils in Maryland. While fertility studies have been done in serpentine areas, little work has been undertaken concerning the genesis of these soils. The objectives of this study were: 1) characterize the properties of soils formed from serpentinite and associated mafic rocks; 2) apply the results of the characterization study to an understanding of the genesis of these soils; and 3) examine the mapping and classification of serpentine soils with reference to geologic mapping.

In a reconnaissance effort, 48 sites were sampled and analyzed for extractable Mg, Ca, P, and K and for pH. From field observations and these data, seven locations were selected for profile descriptions and detailed sampling. Physical, chemical, and mineralogical analyses were conducted on these samples. All serpentine profiles showed weak to moderate expression of argillic horizons and as a result of high Mg saturation, are classified as Alfisols. Argillic horizons in the non-serpentine profiles were strongly developed.

Serpentine minerals were generally abundant in the > 0.2 μm fractions of serpentinite-derived soils. These weather to form expansible 2:1 minerals in the finer fractions. Vermiculite and smectite were important in both serpentine and non-serpentine profiles. The presence of quartz, mica, and feldspar in the surface horizons of all profiles indicate that eolian additions have occurred in many counties in the Maryland Piedmont.

Comparison of soil mapping with geologic mapping has revealed large acreages of serpentine soil units mapped over non-serpentine mafic rock. This demonstrates the need to better utilize available geologic information in soil mapping. Serpentinitic mineral families are not currently recognized in any soil series in Maryland. Three of the four serpentine profiles, however, contained high levels of serpentine minerals. There is, therefore, a need to recognize serpentinitic soil families in Maryland in order to better differentiate between soils formed from serpentinite or from non-serpentine mafic rocks.

## PREFACE

. . . And for myself, if in anything I have been either too credulous or too little awake and attentive, or if I have fallen off by the way and left the inquiry incomplete, nevertheless I so present these things naked and open, that my errors can be marked and set aside before the mass of knowledge be further infected by them . . . .

. . . This Instauration of mine . . . is by no means forgetful of the conditions of mortality and humanity . . . . it seeks for the sciences not arrogantly in the little cells of human wit, but with reverence in the greater world . . . .

. . . Lastly, I would address one general admonition to all--that they consider what are the true ends of knowledge, and that they seek it not either for pleasure of the mind, or for contention, or for superiority to others, or for profit, or fame, or power, or any of these inferior things, but for the benefit and use of life, and that they perfect and govern it in charity.

Francis Bacon
1561-1626
(The Great Instauration)

to Judy

whose love and encouragement

has buoyed my spirit

through the struggles and joys

of this study

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# INTRODUCTION

Soils formed from serpentinite first became a subject of study when the general infertility of these areas was noticed. In an attempt to better understand the cause of the infertility, numerous studies were begun, nearly all of which emphasized only the chemical properties related to soil fertility. Ecologists and botanists became interested in serpentine areas as unique environments which harbored specialized populations and varieties of plants. Their consideration of the soil was often superficial and again limited to chemical properties related to plant nutrition. In contrast to the abundance of fertility-related studies, research related to the morphology and genesis of these soils is scant.

In Maryland, serpentinite is located in the eastern piedmont where it has formed from the alteration of magnesium-rich, subsilicic rocks such as dunite, peridotite, and pyroxenite. Approximately 25,000 acres have been mapped in soil units described as having formed from serpentinite residuum. Some of the soils mapped in these units, however, appear to have been formed from non-serpentine mafic rocks. This contrast in parent materials is reflected in the soils by variations in soil properties which could affect land use.

The objectives of this study were: 1) study the morphological, physical, chemical, and mineralogical properties of soils derived from serpentinite and associated non-serpentine mafic rocks; 2) apply the results of the characterization study to an understanding of the genesis of these soils; and 3) examine the distribution and classification of the soils mapped as serpentine soils with reference to geologic mapping.

## REVIEW OF LITERATURE

### Geology of Serpentinite and Associated Rocks in Maryland

#### Definition and Description

The term serpentine refers to a collection of hydrated magnesian phyllosilicate minerals. The three main polymorphs of these minerals are antigorite, chrisotile, and lizardite (Deer et al., 1962). Magnesium occurs primarily in octahedral coordination but it is common for there to be some substitution of ferrous iron, nickel, cobalt, manganese, and zinc. Less often, aluminum, ferric iron, chromium, and titanium occur in octahedral coordination (Faust & Fahey, 1962). The formula for a pure magnesian serpentine is $Mg_3Si_2O_5(OH)_4$. Serpentine usually occurs as a metamorphic alteration of olivines and pyroxenes. Rocks composed primarily of serpentine minerals are called serpentinites and are derived mainly from dunites, peridotites, and pyroxenites. Consequently, serpentinite is commonly associated with these rocks as well as with some mafic rocks.

#### Distribution

In the piedmont of the eastern United States, a belt of serpentinite bodies runs from New Jersey to Alabama (Pearre & Heyl, 1960). Much of the serpentine found in Maryland is

associated with the Baltimore mafic complex, which is an assemblage of mafic and ultramafic rocks in the eastern piedmont. This has been subdivided by Hopson (1964) into two parts. The Laurel belt extends from the western part of Baltimore City south toward Laurel where it becomes overlain by coastal sediments. The Belair belt emerges from coastal sediments in eastern Baltimore City and extends northeast, past Belair, across the Susquehanna River and into Cecil County to Pennsylvania.

There is also an area of serpentinite bodies in Montgomery County in the vicinity of Hunting Hill and Gaithersburg. Although these are located in the midst of Wissahickon material and not in proximity to the Baltimore mafic complex, the origin is believed to be generally the same (Crowley, 1976; Hopson, 1964).

## Plutonic Theory of Origin

Two major theories have been presented to explain the origin of the serpentinite and associated rocks in the Maryland piedmont. A plutonic theory suggests that they are the result of a mafic igneous intrusion into the preexistent metasedimentary rocks of the Glenarm series (Hopson, 1964; Knopf & Jonas, 1929; Pearre & Heyl, 1960; Southwick, 1969). During crystallization, the gravitational settling of ferromagnesian minerals resulted in a layering of mafic and ultramafic materials (Hopson, 1964; Knopf & Jonas, 1929). Prior to and following complete solidification, regional metamorphism forced

the ultramafic material into the surrounding rock along zones of weakness such as bedding planes (Hopson, 1964).

In order to transform peridotite or pyroxenite into serpentine (serpentinization), water must be incorporated into the structure. For the Maryland serpentinites, this water may have been provided in two ways. It may either have been present in the magma itself, or, more likely, it was provided by the surrounding intruded metasediments (Hopson, 1964).

According to this plutonic theory, the Montgomery County serpentine bodies had a similar origin to those to the east. According to Hopson (1964), these bodies were detached from the parent masses and deposited as a result of regional metamorphism and solid intrusion. Discussing the Hunting Hill body, Larabee (1969) suggests that a semisolid dunite intruded Wissahickon material during Ordovician time. After solidification, the dunite was intruded by gabbro dikes. Metamorphism of the dunite resulted in serpentinite while the gabbro dikes were altered to rodingite.

Tectonic Theory of Origin

Crowley (1976) has proposed an alternative theory for the origin of Maryland serpentinite and associated rocks. He suggests that the evidence does not support an intrusive igneous origin. Geologic mapping of this area indicates that the rocks of the Baltimore mafic complex do not occur in materials stratigraphically below the Wissahickon formation and therefore could not be intruded from lower levels.

It is suggested that mafic and ultramafic volcanic rocks at the seafloor underwent serpentinization when overlying seawater entered zones of faulting, which were then subjected to heat and pressure. Converging continental plates caused thrust faulting which forced these rocks into early Wissahickon material (Crowley, 1976).

## Montgomery County Diabase

Somewhat west of the Montgomery County serpentinite bodies near Boyds, is an area of mafic rock which, while chemically similar to some gabbros, is probably not genetically related to the previously mentioned rocks. It is described by Fisher (1964) as a diabase sill of about three and a half square miles in area and two hundred to seven hundred feet thick, which had intruded an unconformity between Wissahickon material and sedimentary rock of Triassic age.

## Geomorphology of Serpentinite Areas

The serpentinite and associated mafic bodies occur with those of the Glenarm group on the undulating uplands of the piedmont plateau. The general landscape is characterized by rounded hills with U-shaped valleys (Johansen, 1928). In his description of the Conowingo serpentine barrens of southeastern Pennsylvania, Pernell (1910) observed the serpentine occurring at hillcrests and as low ridges. He attributed this location to the "chemical stability" or resistance to weathering of the serpentinite.

In their study of the Soldiers Delight serpentinite body in Baltimore County, Maryland, Cleaves et al. (1974) stated that there was no topographic distinction indicating the boundary between the serpentinite and adjacent Wissahickon schist. This indicated that the overall rates of denudation of these two rock types were comparable. They did, however, describe distinct local differences in topography reflecting contrasts in the style of denudation. The terrain on the schist was more deeply and extensively dissected than the serpentine areas. This supported their conclusion that mechanical weathering was more significant on the Wissahickon materials while chemical weathering was more important on the serpentinite.

Larabee's (1969) observations of the Montgomery County areas were similar to those of Cleaves et al. (1974). In contrasting serpentines to surrounding schists, he also described the area as being much less dissected and marked by broad gentle slopes.

A cursory comparison of topographic maps of Montgomery (Weaver, 1950b), Baltimore (Weaver, 1948a), Harford (Weaver, 1948b), and Cecil (Weaver, 1950a) counties with the state geologic map (Weaver, 1968) leads to similar conclusions. It appears that landscapes overlying serpentinite and other ultramafic rocks are, with some exceptions, generally less dissected than surrounding areas.

## Soil Profile Morphology

Reports of soils formed from serpentinite parent material suggest a wide range in profile characteristics. Some generalizations, however, may be made from the literature.

### Depth of Soils

Most serpentine soils of temperate regions, and some in tropical areas, are shallow to bedrock (Lee et al., 1974). In a study of serpentinite-derived soils in England, Coombe and Frost (1956) described two soils which encountered bedrock within 50 cm of the surface. The Dubakella soil series described by Wildman et al. (1968) in central California is commonly about 65 cm deep to serpentine bedrock (National Cooperative Soil Survey, 1971). In the official description by the National Cooperative Soil Survey (1970) of the Chrome series in southeastern Pennsylvania, the depth to serpentine bedrock ranges from 50 to 100 cm.

In Maryland, several researchers have described shallow soils overlying serpentinite. While Johansen (1928) observed soils in the serpentine barrens of Harford County to be only 15 to 20 cm deep, Perkins and Winant (1931) and Smith and Matthews (1975) have reported the depth of serpentine-derived soils in the county to range from 40 to 75 cm and 50 to 100 cm, respectively. Descriptions of soils formed from serpentinite in other Maryland counties also show a shallow depth to bedrock (Andersen & Matthews, 1973; Matthews et al., 1960; Reybold & Matthews, 1976).

Some workers have reported deeper serpentine soils. Coombe and Frost (1956) described one profile in England which was considerably deeper than other local serpentinite-derived soils. Mineralogical analyses revealed that the greater depth was due to loess additions. Additional evidence for eolian contributions to serpentine soils in England and Scotland was submitted by Proctor and Woodell (1971). Smith and Matthews (1975) also suggest that the Aldino soil of Harford County, Maryland, which is about 125 cm deep to bedrock, is formed primarily from serpentine but has sustained loess additions.

Tropical soils formed from serpentinite have been reported to be shallow in some instances and deep in others. Bennett and Allison (1928) described three serpentine soils in Cuba. Two of the three encountered bedrock within 75 to 125 cm of the surface. In the third soil, however, the saprolite extended to nearly five meters before reaching hard rock. In a serpentinite-derived soil in Puerto Rico, the C1 horizon extended to a depth of nearly two meters; the depth to hard rock was not indicated (Soil Survey Staff, 1975).

Earlier workers believed serpentinite to be highly resistant to weathering (Pernell, 1910). This was stated as the explanation for shallow soils so commonly reported. Cleaves et al. (1974), however, have shown the rate of chemical weathering of serpentinite in Maryland to be greater than materials of the Wissahickon formation. They state that the lack of resistant minerals in the serpentinite, such as quartz

and muscovite, precludes their accumulation as soil or saprolite. This would account for the shallow soils and lack of a deep saprolite mantle.

## Horizonation

In their study of four serpentine soils in California, Wildman et al. (1968) reported a considerable increase in percent clay from the A to the B horizon. This has been interpreted to indicate the presence of an argillic horizon (Soil Survey Staff, 1977). Argillic horizons have been shown to be present in all but the most shallow serpentine soils in Maryland (Andersen & Matthews, 1973; Matthews et al., 1960; National Cooperative Soil Survey, 1972; Perkins & Winant, 1931; Smith & Matthews, 1975). Saprolite, if present at all in these soils, is limited to a relatively thin layer.

Tropical soils of serpentine derivation are generally high in clay and may or may not have argillic horizons (Soil Survey Staff, 1977). Descriptions of serpentine soils in Cuba by Bennett and Allison (1928) state that the texture throughout the solum is clay. This is supported by the report of the Soil Survey Staff (1975) of a serpentinite-derived soil in Puerto Rico where the clay content throughout the solum was 55 to 60 percent.

## Coarse Fragment

Many soils formed from serpentinite contain coarse fragments throughout the profile. Wildman et al. (1968)

reported serpentine gravels in all horizons of four soils in California. Some serpentine soils in the British Isles were described as very stony (Proctor & Woodell, 1971). Rock outcrops are common in Maryland serpentine soils and approximately 20 percent of these soils in the State have been mapped in very stony or channery phases (Andersen & Matthews, 1973; Matthews et al., 1960; Perkins & Winant, 1931; Reybold & Matthews, 1976; Smith & Matthews, 1975).

## Chemical Properties of Serpentine Soils

### Soil Reaction

Due to the large number of fertility studies, many workers have reported on the chemical properties of soils formed from serpentine rock. The pH of these soils is generally slightly acid to moderately alkaline (Soil Survey Staff, 1951). Four reports indicate that the pH of the surface horizon of serpentinite-derived soils of California range from about 6.4 to 8.2 (Gordon & Lipman, 1926; Jones et al., 1977; Martin et al., 1953; Walker, 1954). Descriptions of serpentine soils in Rhodesia, Scotland, and England showed that the pH values were similarly high (Proctor, 1971; Shewry & Peterson, 1976; Soane & Saunder, 1959).

The pH of these soils tends to increase with depth in the profile. Data from four profiles in Poland by Sarosiek (1964) demonstrate this. Data reported by workers in Japan and Maryland also show this trend (Kanno et al., 1965b; Robinson et al., 1935).

Major Nutrients

The three basic ions which dominate exchange sites in serpentine soils are $Mg^{++}$, $Ca^{++}$, and $K^{+}$. A few researchers report small amounts of $Na^{+}$ (Jones et al., 1977; Kanno et al., 1965b; Martin et al., 1953; Robinson et al., 1935). Potassium, generally, is present on the exchange complex only in small amounts. Values reported for $K^{+}$ range from 0.03 to 1.0 meq/100g, but most commonly are about 0.2 meq/100g and occupy a very small percentage of the exchange complex (Jones et al., 1977; Robinson et al., 1935).

The range in values reported for exchangeable $Ca^{++}$ and $Mg^{++}$ is very wide, being 0.1 to 8.33 meq/100g and 0.37 to 37.5 meq/100g, respectively (Martin et al., 1953; Proctor, 1971; Robinson et al., 1935). Almost universally, the exchangeable $Mg^{++}$ is much greater than the exchangeable $Ca^{++}$ for any one soil. It is not uncommon for 75 to 90 percent of the exchangeable bases to be $Mg^{++}$ (Kanno et al., 1965b; Sarosiek, 1964; Shewry & Peterson, 1975). Calcium usually occupies a small percentage of the exchange complex.

Data presented by Kanno et al. (1965b), Martin et al. (1953), and Sarosiek (1964) show that the amounts of exchangeable $Ca^{++}$ and $Mg^{++}$ vary with depth. Magnesium values tend to increase with depth and proximity to the parent rock while calcium values increase toward the soil surface.

Phosphorous levels are usually low in soil derived from serpentinite, although some exceptions exist. Five researchers

reporting on soils from four geographical locations (California, Britain, Poland, and New Zealand) all reported similarly low levels of available P. These ranged from less than 4 ppm to 18 ppm available $P_2O_5$ (Birrel & Wright, 1945; Jones et al., 1977; Proctor, 1971; Sarosiek, 1964; Spence & Millar, 1963). In contrast, Soane and Saunder (1959) reported that the available $P_2O_5$ in eight serpentine soils in southern Rhodesia ranged from 60 to 220 ppm; the mean value was 137 ppm.

Heavy Metals

One of the peculiarities of serpentinite-derived soils is the unusually high levels of Ni and Cr that have been reported. Shewry and Peterson (1976) reported values for exchangeable $Ni^{++}$ in eight soils from 0.9 to 9.0 ppm while exchangeable $Ni^{++}$ and $Cr^{+++}$ in two non-serpentine soils were less than 0.1 ppm. Several other workers have reported values for exchangeable $Ni^{++}$ from 0.6 to 70 ppm (Robinson et al., 1935; Sarosiek, 1964; Soane & Saunder, 1959; Walker, 1954).

Sarosiek (1964) reported values for extractable (2% HCl) Cr of 12 to 54 ppm. Robinson et al. (1935) reported values of 0.1 to 1.4 ppm exchangeable $Cr^{+++}$ for serpentine soils. These values are considerably higher than those reported for non-serpentine soils by other workers (Robinson et al., 1935; Shewry & Peterson, 1976). Work by Walker (1954) and Shewry and Peterson (1976), however, has shown levels of exchangeable $Cr^{+++}$ to be no higher than for non-serpentine soils.

Data for three of four profiles described by Sarosiek (1964) indicate that extractable (2% HCl) Ni and Cr increase with depth in the profile.

Total Ni and Cr values for serpentine soils have been reported by many workers. Soil levels in several localities ranged from 830 to 3,000 ppm Ni and from 765 to 27,000 ppm Cr (Lee et al., 1975; Lyon et al., 1971; Proctor, 1971; Proctor & Woodell, 1971; Robinson et al., 1935; Shewry & Peterson, 1976; Soane & Saunder, 1959). Values for non-serpentine soils were 10 to 35 ppm total Ni and 30 to 165 ppm total Cr (Lyon et al., 1971; Shewry & Peterson, 1976).

Profiles described by Kanno et al. (1965b) showed an increase in total Ni with depth. Values for Cr, however, showed no such trend. Although the values reported by Sarosiek (1964) were lower than those of other workers, three of four profiles described showed increasing values for total Ni and Cr with depth.

## Mineralogical Properties of Serpentine Soils

The mineralogy of four California serpentinite-derived soils has been described by Wildman et al. (1968). They found serpentine minerals to dominate the > 0.2μm fractions while an iron-rich smectite dominated the < 0.2μm fraction. The formation of an iron-rich smectite mineral rather than the magnesium-rich saponite is explained by the greater stability of $Fe(OH)_3$ and $Al(OH)_3$ than $Mg(OH)_2$ in the octahedral sheet under soil

conditions. This is true even though the parent material is very high in Mg and $Mg^{++}$ dominates the cation exchange complex (Wildman et al., 1971).

In a serpentinite-derived soil in Italy, Veniale (1963) described a smectite mineral interstratified with a swelling chlorite. Chemical analyses suggested that the smectite was saponite which had formed from the serpentinite. Some clay-sized serpentine was also found throughout the profile.

Veniale and van der Mavel (1963) described a serpentine soil in Borneo which was weathered to a depth of 7.5 meters. Montmorillonite formed during the initial stages of weathering and was present only in the first one-half meter above the bedrock. Serpentine minerals were also found only in the lowest portion of the profile. Some chlorite, which was present in the parent material, was found in the three meters of material overlying the bedrock. Kaolinite appeared to be forming as an end phase and was present in the surface meter of soil. Due to the intense weathering environment, goethite and gibbsite were present throughout the profile.

Profiles of two serpentine soils in Japan were described by Kanno et al. (1965a). In one of the profiles, the dominant clay minerals were antigorite and a 14Å mineral which was not further identified. The clay mineralogy of the second profile was dominated by the same 14Å mineral. Some antigorite was reported in the A horizon and another 7Å mineral, which was not further identified, was present in the B horizon.

## Fertility and Vegetation

The infertility of serpentine soils has been recognized for many years, and the distinctive appearance of these areas has been reported by numerous people. Describing the serpentine areas in Harford County, Johansen (1928) writes:

> In the serpentine areas, however, the trees are stunted, and the fact that he is walking or driving over a serpentine area is brought forcibly to the notice of the traveller during the summer by the intense heat of the sun, which beats down through a growth of stunted oaks, scrub pines and mountain laurel upon the heated soil, through which everywhere project boulders of the country rock. These areas are known throughout the country as the serpentine barrens. Wild, uncultivated, almost unsettled, they stand in great contrast to the surrounding rich and prosperous country.

Isaac Tyson Jr. was the first to be credited with recognizing the association of poor and stunted vegetation with serpentine rocks. During the first part of the nineteenth century, this observation enabled him to monopolize the chrome industry for a while through purchasing land across the state underlain by the chromite-rich serpentinite, using the characteristic vegetation as an indicator (Singewald, 1928). Although the infertility of these areas has been long known, the cause of infertility has been the subject of much controversy.

As early as 1901, Loew (1901) and May (1901) reported that their investigations had shown that an optimum soil Ca to Mg ratio exists for each plant and that deviation from this optimum ratio, especially excess Mg, would be detrimental

to the plant. Although Lipman (1916) published a critique of this Ca : Mg ratio theory, indicating that there was as much evidence opposing the theory as supporting it, others began to apply the theory. Blackshaw (1921) was the first to explain serpentine infertility on the basis of the Ca : Mg ratio. He linked the infertility of Rhodesian serpentine soils to a low Ca : Mg ratio. In a study of four serpentine soils from Scotland, Proctor (1971) also concluded that the infertility was due to a low Ca : Mg ratio. Work by Walker et al. (1955) also supported this theory.

In a pot study using ten serpentine soils located near San Francisco, Gordon and Lipman (1926) concluded that the major causes of infertility were N and P deficiencies. They found no evidence that an excess of Mg over Ca was responsible for inhibiting plant growth. In a similar study examining plant growth on a Scottish serpentine soil, Spence and Millar (1963) also concluded that the main cause of infertility was P deficiency in conjunction with low levels of K and N.

Harshberger (1903) suggested that the characteristic vegetation on serpentine soils was the result of xerophytic plants growing on a very shallow soil. Johansen (1928) also hypothesized that the infertility may be due to the low water-holding capacity of the shallow serpentine soils.

Robinson et al. (1935) analyzed serpentine soils from six states plus Cuba and Puerto Rico and compared these to non-serpentine soils. They concluded that:

> The most conspicuous difference between the fertile non-serpentine and the infertile (serpentine) soils, is the absence of chromium and nickel in the non-serpentine soil.

Several other workers have also reported the cause of serpentine infertility to be toxic levels of Ni and Cr in the soil (Birrel & Wright, 1945; Crooke, 1956; Halstead, 1968; Soane & Saunder, 1959; Spence, 1957).

Vlamis and Jenny (1948) conducted a series of pot experiments using a California serpentine soil. The results indicated that the main cause of infertility was a Ca deficiency rather than an improper Ca to Mg ratio. Martin et al. (1953) conducted a field experiment which further supported this theory.

In serpentine soils collected from Sweden and Scotland, Mg was reported to be present at levels sufficient to be toxic according to Marrs and Proctor (1976). They suggested that Mg toxicity, rather than low Ca to Mg ratios could be the primary cause of infertility on these soils.

In light of the numerous theories suggested to explain serpentine infertility, it appears that many factors may be involved and that there is no single universal cause. Depending on such factors as heavy metal content of the parent rock, purity of the serpentinite parent material, and soil pH, the particular cause of infertility may vary. The theories of infertility may be placed into three general groups which are 1) deficiency of major nutrients, 2) imbalance of Mg and Ca, and 3) heavy metal toxicity. The infertility at a given location may be due to any one or a combination of these causes.

# METHODS AND MATERIALS

## Field Procedures

### Reconnaissance Sampling

Utilizing state and county geology maps (Clark, 1902; Cloos & Cooke, 1953; Matthews, 1925; Southwick & Owens, 1968; Weaver, 1968) and county soil survey reports to locate areas of serpentine soils, samples from 48 locations were collected using a standard 7.5 cm diameter bucket auger. One to nine samples at various depths in the same profile were collected from each location. Any notable soil characteristics, as well as the dominant vegetation present at each site, were recorded. Figure 1 shows the location of sampling sites.

### Selection of Site Locations for Profile Descriptions

Both chemical and morphological data collected during reconnaissance sampling were used in selecting sites for profile descriptions and detailed sampling. Seven sites were chosen to represent the range in location and characteristics of soils formed from serpentinite and associated rocks. The locations of these profile sites are shown in Figure 2. Soils at four of the locations were developed from serpentinite and three were developed from non-serpentine mafic rocks.

At each of the selected sites, pits were opened and descriptions were made according to standard procedures

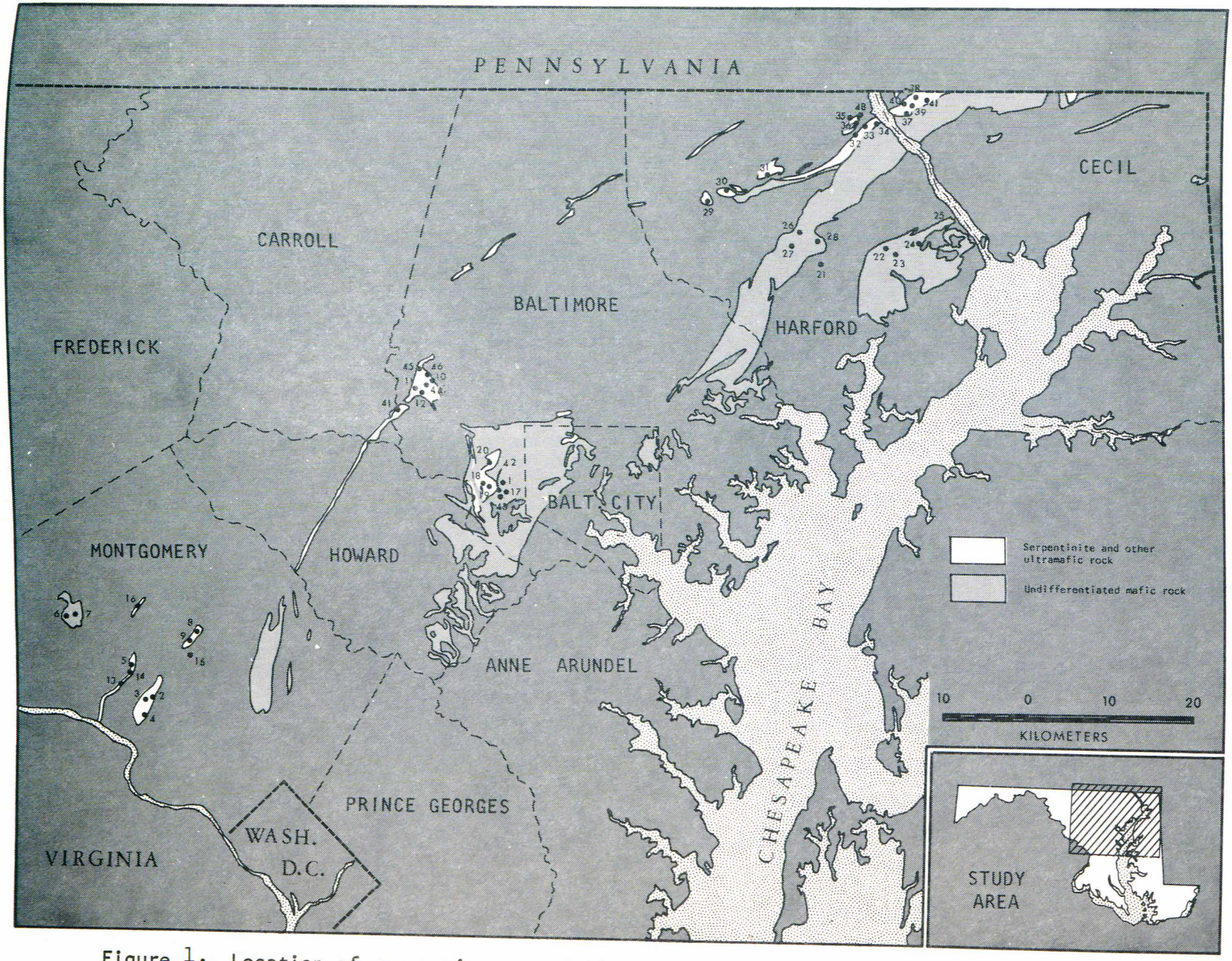



Figure 1. Location of reconnaissance sampling sites for serpentine soil investigations.

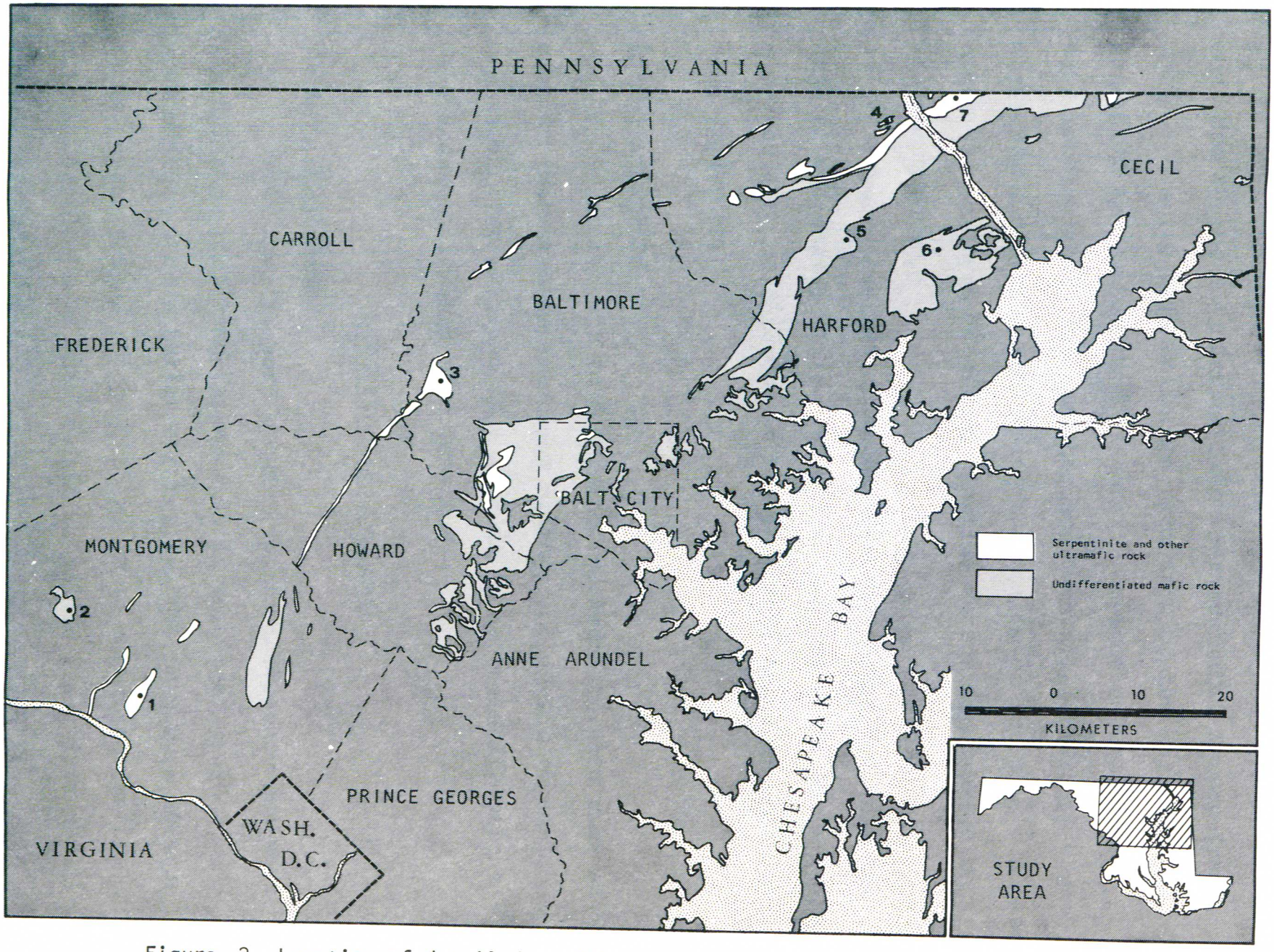



Figure 2. Location of detailed profile sampling sites shown in relationship to ultramafic and mafic geology.

outlined by the Soil Conservation Service (Soil Survey Staff, 1951). Samples were collected from each of the horizons described to the bottom of the pit. In some cases two or more subsamples of the same horizon were collected. In cases where the bedrock existed below the bottom of the pit, a bucket auger was employed to collect samples to the depth where rock was encountered.

Where possible, rock samples were collected from the base of the soil profile. When this was not possible, samples from boulders or outcrops in the immediate sampling vicinity were collected.

### Seismic Analyses

In an attempt to determine the depth to hard rock at each of the seven locations, a seismograph (R-150 Terra-Scout) was used. Two straight line courses in opposite directions were measured at each site location.

## Laboratory Procedures

### Sample Preparation

Soil samples were brought to the laboratory and were air dried at room temperature. Soils were then crushed by hand using a wooden mallet and rolling pin to pass a 10 mesh (2 mm) nylon sieve. Fragments >2 mm in diameter were removed. Samples were then stored in sealed glass jars until needed for analysis.

## Particle Size

The particle size distribution was determined on the samples from each of the profiles described. The pipette method, as described by Kilmer and Alexander (1949) and Day (1965), was employed in the determination of the silt and clay fractions. Sand fractions were determined gravimetrically after sieving.

## Potential Volume Change

The measurement of potential volume change was conducted on the B horizons of each of the profiles sampled using the FHA PVC meter. The procedure followed in these determinations is reported in FHA Pub. No. 595 (Henry & Drago, 1965). Air dry soil (< 2 mm) was compacted and then wetted. The pressure exerted from the expansion on wetting was read from a proving ring dial. Swell index and potential hazard were estimated from calibration graphs in FHA Pub. No. 701 (Lambe, 1960).

## Extractable Nutrients

All samples collected were sent to the University of Maryland Soil Testing Laboratory for determination of extractable P, K, Ca, and Mg. The procedure used was a double weak acid extraction procedure reported by Bandel and Rivard (1975).

## Soil Reaction

The pH of all samples collected was determined on a 1:1 soil:distilled water mixture. Twenty grams of air dry soil and 20 ml of distilled water were mixed and allowed to equilibrate for 30 minutes. The pH was then determined using a Beckman pH meter equipped with a glass electrode.

## Exchangeable Cations

Exchangeable $Ca^{++}$, $Mg^{++}$, $K^{+}$, and $Ni^{++}$ were determined on the samples from the seven profiles. Preliminary measurements of $Na^{+}$ showed only trace levels to be present; determinations were therefore not made. Displacement of the cations followed a slightly modified version of Chapman's (1965) procedure. Ten grams of air dry soil was slowly leached with 100 ml of neutral 1N $NH_4OAC$ which was collected in a volumetric flask. Exchangeable cations were then determined on the leachate using atomic absorption techniques with a Varian Techtron model 1200 atomic absorption spectrophotometer.

## Exchangeable Acidity

Exchangeable acidity of all profile samples was determined using the $BaCl_2$-triethanolamine method as outlined by Peech (1965).

## Cation Exchange Capacity

The cation exchange capacity of all profile samples was determined in two ways. A slight modification of Chapman's

(1965) method was used for saturation and displacement of $NH_4^+$ on and from the exchange complex. Two and one half grams of "celite" analytical filter aid was added to the ten grams of each soil sample to increase the rate of filtration. Two and one half grams of celite was also used in a "blank" which was subjected to the full analysis procedure. Two blanks were included for every 16 samples run. The exchangeable $NH_4^+$ was then determined using the Kjeldahl procedure (Bradstreat, 1954).

The cation exchange capacity was also determined by summation (Chapman, 1965). This was done by summing the exchangeable $H^+$ as determined by the $BaCl_2$-triethanolamine method and the exchangeable bases as displaced by neutral 1N $NH_4OAC$.

Total Soil Analyses for Metals

Samples from the four serpentinite-derived profiles were analyzed for total Ni, Cr, and Fe using a modification of Pratt's (1965) procedure. One half gram of finely ground (< 60 mesh) soil was weighed to the nearest 0.1 mg into a platinum crucible. Six ml of concentrated $HNO_3$ was added and the contents of the crucible were evaporated to dryness on a 100°C sandbath. Ten ml of concentrated HF and one ml of concentrated $HClO_4$ were added to the crucible which was then evaporated to dryness on a 200°C sandbath. This step was repeated using 5 ml of HF and 0.5 ml of $HClO_4$. The residue was

then dissolved in 25 ml of 6 N HCl and transferred to a 250 ml volumetric flask which was brought to volume. Concentrations of Ni, Cr, and Fe in solution were then measured using atomic absorption techniques.

X-ray spectrographic techniques were used to determine total Ni and Fe levels in the three non-serpentine profiles. Pellets were prepared from these samples according to the procedures of Keramidas and Fanning (1976). Samples from the serpentine profiles, for which total Ni and Fe had been previously determined, were used as standards. A Phillips four-position inverted spectrograph equipped with a flow proportional counter and LiF crystal was employed in the determinations. Equipment settings for Ni determinations are the same as those of Keramidas and Fanning (1976) and settings for Fe determinations are the same as those of Fanning et al. (1970).

Elemental Analyses of Silts

Coarse (20-50 μm) and fine (2-20 μm) silts were separated and collected by sedimentation techniques from profile samples. X-ray spectroscopic methods were employed to determine the total levels of Fe, Zr, Ti, Ca, and K present in these fractions. Sample preparation and equipment settings were the same as those of Wright (1972). Standard pellets from NBS samples 76, 77, 78, 97, and 102, which were made by Wright, were used in this study. Pellets which Wright used to establish low ranges in CaO and high ranges in $Fe_2O_3$ were

used as well. Some pellets used as standards for very high ranges of $Fe_2O_3$ were prepared by adding 99.99% $Fe_2O_3$ to NBS samples.

## Organic Carbon

The percentage of organic carbon was determined on selected samples using the Walkley-Black wet oxidation technique as reported by Allison (1965). A correction factor of 1.33 was used. Values were determined for the surface horizon, the horizon directly underlying the surface horizon, and a subsoil horizon for each of the profiles sampled.

## Free Iron Oxides

Determinations of free iron oxides were made on samples from all of the profiles described utilizing a slight modification of the technique reported by Fanning et al. (1970). One gram of soil was crushed, using an agate mortar and pestle, to pass a 60 mesh sieve. Crushing was necessary due to the presence of Fe oxides in concretionary form. After the sodium dithionite treatment, the extractant was brought to volume in a 100 ml volumetric flask and analyzed using the spectrographic method reported.

## Mineralogy of Soils

The mineralogy of the coarse (0.2-2 μm) and fine (< 0.2 μm) clay and fine (2-5 μm) silt was determined using X-ray diffraction methods similar to those of Jackson (1969).

After removal of organic matter by treatment with $H_2O_2$ and free iron oxides by treatment with sodium dithionite, particle size fractionations were made using an International Model PR-2 portable refrigerated centrifuge. Fractions were collected in order of increasing particle size. Thirty mg samples were then K and Mg saturated, glycerol solvated, and mounted on glass slides for parallel orientation according to Jackson (1969).

X-ray diffraction patterns were recorded using a Phillips X-ray diffractometer equipped with a proportional counter and a single crystal monochrometer. Cobalt Kα radiation was used; the Kβ radiation was eliminated by the monochrometer. Using a scanning rate of 2°2θ per minute, scans were made from 4° to 36° 2θ. Other machine specifications and settings include: receiving slit 1°; divergent slit ¼°; 35 kv tube voltage and 18 ma tube current; 4 second time constant; detector voltage of 1.7 kv; integral pulse height analysis setting with 10 volt base line.

Each sample was run under the following conditions: Mg saturation and glycerol solvation at 25°C; K saturation and glycerol solvation at 25°C; K saturation with heating to 300°C for 2 hours; K saturation with heating to 550°C for 2 hours.

## Mineralogy of Parent Materials

X-ray diffraction analyses were conducted on rock samples from the various sites described. The rock samples were secured from one of three locations with respect to the

sampling sites: 1) bedrock directly underlying the soil; 2) coarse fragment from the lower soil horizons; 3) boulders or outcrops in the immediate vicinity. Each sample was finely ground using an agate mortar and pestle. Randomly oriented samples were then analyzed in one of two ways.

A Phillips Debye-Scherrer type 57.3 mm diameter powder camera was used in the analysis of some samples. Each powdered sample was placed in a 0.2 mm ID glass capillary tube and then centered in the camera. The camera was loaded with 35 mm X-ray film and exposed for one to three hours to $CoK\alpha$ radiation using a Phillips X-ray diffractometer equipped with an Fe filter. The film was developed according to specifications and then interpreted using values of Smith (1965) and Berry (1974).

Other samples were analyzed with a standard diffraction arrangement using a box mount slide as described by Jackson (1969). A Phillips X-ray diffractometer equipped with a single crystal monochrometer and proportional counter was used. Equipment settings were the same as previously described for analysis of soils.

# RESULTS AND DISCUSSION

## Genesis and Characterization

### Seismographic Analysis and Soil Depth

Seven soil profiles in the eastern Piedmont of Maryland were described and sampled to the depth at which rock was encountered. In some instances the rock was thought to be bedrock while in other cases smaller rocks or boulders were probably present which prevented deeper sampling with a bucket auger. Complete field descriptions were made indicating the maximum depth of sampling. Profiles 1, 3, 4, and 7 were developed from serpentinite residuum while profiles 2, 5, and 6 formed from various non-serpentine mafic rocks.

The thickness of the sola in the non-serpentine profiles appeared to be greater than those of the serpentinite-derived soils. The maximum depth of sampling also appeared to be greater for the non-serpentine profiles. These shallow serpentine profiles are in accord with the reports of other workers who have studied serpentine soils in Maryland and other temperate regions (Andersen & Matthews, 1973; Cleaves et al., 1974; Coombe & Frost, 1956; Matthews et al., 1960; Reybold & Matthews, 1976; Smith & Matthews, 1975; Wildman et al., 1968).

Profile 1
Aldino silt loam
S 76 Md 15-1
Aquic Hapludalf - fine silty, mixed, mesic

| Horizon | Depth cm | Description |
|---|---|---|
| A1 | 0-6 | Dark grayish brown (2.5Y 4/2) silt loam; weak medium granular structure; friable; roots abundant; a few iron-manganese concretions; medium acid; clear smooth boundary. |
| Ap | 6-21 | Brown (10YR 5/3) silt loam; moderate medium granular structure; friable; roots abundant; iron-manganese concretions common; strongly acid; abrupt smooth boundary. |
| A2 | 21-26 | Pale brown (10YR 6/3) silt loam; few fine faint yellowish brown (10YR 5/4) mottles; moderate medium granular structure; medium acid; abrupt wavy boundary. |
| B2t | 26-38 | Yellowish brown (10YR 5/4) heavy silt loam in upper part to silty clay loam in lower part; common fine faint (10YR 5/6, 5/8) mottles; moderate fine subangular blocky structure; friable; roots common; iron-manganese concretions common; thin discontinuous clay films on ped faces; medium acid; clear wavy boundary. |
| B&C | 38-60 | Yellowish brown (10YR 5/4) variable silt loam, silty clay loam, and gravelly loam; many medium distinct strong brown (7.5 YR 5/8) and light brownish gray (10Y 6/2) mottles; moderate fine subangular blocky structure in silty clay loam pockets to weak medium subangular blocky in silt loam portions; firm consistence in silty clay loam pockets, friable elsewhere; few roots; iron-manganese concretions abundant in pockets resulting in gravelly loam texture; thick continuous clay films on ped faces in heavier portions of the horizon; neutral; shattered bedrock fragments common. |
| R | 60+ | Serpentinite bedrock. |

| | |
|---|---|
| Location: | Montgomery County, Maryland; ¼ mile northeast of intersection of Travillah Rd. and Piney Meetinghouse Rd., 50 yards south of Travillah Rd. in an abandoned field. |
| Vegetation: | Broomsedge (Andropogan virginicus) and other mixed grasses and weeds with some small Virginia pine (Pinus virginiana) and Red Cedar (Juniperus virginiana) trees. |
| Parent Material: | Serpentinite residuum. |
| Physiography: | Piedmont upland. |
| Slope: | 4%, southern aspect. |
| Elevation: | 135 meters. |
| Drainage: | Somewhat poor. |
| Erosion: | None to slight. |
| Permeability: | Moderate to slow. |
| Groundwater: | Perched water table over bedrock, 60 cm. |
| Described by: | M.C. Rabenhorst and J.E. Foss. |
| Date: | 10/27/76 |
| Remarks: | This profile does not fit the modal concept of the Aldino series because: 1) absence of a fragipan; and 2) the presence of low chroma mottles in the upper 25 cm of the argillic horizon. |

Profile 2
Iredell silt loam
S 76 Md 15-2
Typic Hapludalf - fine, mixed, mesic

| Horizon | Depth cm | Description |
|---|---|---|
| 01 | 1-0 | Thin layer of pine needles and dead grass. |
| A1 | 0-11 | Brown (10YR 4/3) silt loam; weak fine subangular blocky structure; friable; medium acid; clear smooth boundary. |
| A2 | 11-18 | Yellowish brown (10YR 5/4) silt loam; weak fine subangular blocky structure; friable; medium acid; clear smooth boundary. |
| B1 | 18-29 | Yellowish brown (10YR 5/6) clay loam; common fine faint (10YR 5/4) mottles; moderate fine subangular blocky structure; friable; thin continuous clay films on vertical ped faces; medium acid; clear smooth boundary. |
| B21t | 29-45 | Yellowish brown (10YR 5/6) clay; common fine faint strong brown (7.5YR 5/6) and yellowish brown (10YR 5/4) mottles; moderate fine subangular blocky structure; friable; thin continuous clay films on vertical and horizontal ped surfaces; medium acid; gradual smooth boundary. |
| B22t | 45-54 | Yellowish brown (10YR 5/4) clay loam; common fine distinct brown (10YR 5/3) and strong brown (7.5YR 5/6, 5/8) mottles; some black manganese stains present; moderate medium subangular blocky structure; firm; thin continuous clay films on vertical and horizontal ped faces; slightly acid; clear smooth boundary. |
| B3 | 54-75 | Yellowish brown (10YR 5/2) loam; common fine distinct grayish brown (10YR 5/2) and yellowish brown (10YR 5/6, 5/8) mottles; moderate medium to coarse platy structure; firm; thin discontinuous clay films on horizontal ped faces; neutral; clear smooth boundary. |
| C1 | 75-92 | Yellowish brown (10YR 5/4) loamy coarse sand; weak medium platy structure in the upper part, rock structure in the lower portion; neutral. |

| Horizon | Depth cm | Description |
|---|---|---|
| C2 | 92-110 | Olive brown (2.5Y 4/4) coarse sand; neutral. |
| C3 | 110-138 | Yellowish brown (10YR 5/6) coarse sandy loam; neutral. |
| C4 | 138-154 | Light olive brown (2.5Y 5/4) coarse sandy loam; neutral. |

Location: Montgomery County, Maryland; on Hoyles Mill Rd. about 3/4 mile south of the intersection with Maryland Rt. 121, on the east side of road in wooded area.

Vegetation: Mixed forest of Virginia Pine (*Pinus virginiana*), various Oaks (*Quercus* sp.) and Red Cedar (*Juniperus virginiana*).

Parent Material: Diabase residuum.

Physiography: Piedmont upland sideslope.

Slope: 8%, northwest aspect.

Elevation: 90 meters.

Drainage: Somewhat poor.

Erosion: None to slight.

Permeability: Slow.

Groundwater: Perched water table; seepage above the B3 horizon.

Described by: M. C. Rabenhorst and J. E. Foss.

Date: 10/27/76

Remarks: This profile does not fit the modal concept of the Iredell series because: 1) mixed rather than montmorillonitic mineralogy; and 2) Mesic temperature regime.

Profile 3
Chrome silt loam
S 76 Md 3-1
Typic Hapludalf - fine silty, serpentinitic, mesic

| Horizon | Depth cm | Description |
|---|---|---|
| A1 | 0-4 | Dark brown (10YR 3/3) silt loam; weak fine granular structure with weak platy tendency; friable; strongly acid; clear smooth boundary. |
| A2 | 4-16 | Brown (10YR 5/3) silt loam; weak medium subangular blocky structure; friable; a few iron-manganese concretions; medium acid; clear smooth boundary. |
| B1 | 16-28 | Yellowish brown (10YR 5/6) silt loam; moderate medium subangular blocky structure; friable; iron-manganese concretions are common; medium acid; clear smooth boundary. |
| B21t | 28-40 | Yellowish brown (10YR 5/4) silty clay loam; few fine faint (10YR 5/6) mottles; strong fine subangular blocky structure; friable; thin continuous clay films on ped faces; slightly acid; clear smooth boundary. |
| B22t | 40-53 | Brown (10YR 4/3) silty clay loam; many fine distinct yellowish brown (10YR 5/6) and strong brown (7.5YR 5/6) mottles; moderate medium subangular blocky structure; friable; thin continuous clay films on ped faces; slightly acid; gradual smooth boundary. |
| B3 | 53-75 | Yellowish brown (10YR 5/6) silty clay loam; common medium distinct brown (10YR 5/3) mottles; weak medium subangular blocky structure with some platy tendency; friable; slightly acid. |
| C1 | 75-107 | Strong brown (7.5YR 5/6) loam; common medium prominent brownish yellow (10YR 6/6), grayish brown (2.5Y 5/2), and dark grayish brown (2.5Y 4/2) mottles; slightly acid. |
| C2 | 107-123 | Yellowish brown (10YR 5/6) loam; common fine prominent brownish yellow (10YR 6/6), brown (7.5YR 4/4), and grayish brown (2.5Y 5/2) mottles; neutral. |

| Horizon | Depth cm | Description |
|---|---|---|
| C3 | 123-155 | Yellowish brown (10YR 5/6) silt loam; common fine prominent brown (7.5YR 4/4), brownish yellow (10YR 6/6), and grayish brown (2.5Y 5/2) mottles; neutral. |
| C4 | 155-170 | Yellowish brown (10YR 5/6) silt loam; common fine distinct olive brown (2.5Y 5/4) mottles; neutral. |

Location: Baltimore County, Maryland; Soldiers Delight at the Deer Park overlook, in a wooded area on the northeast side of the road, 110 yards in from the road.

Vegetation: Mixed forest of Virginia Pine (Pinus virginiana), Blackjack Oak (Quercus marilandica), Greenbriar (Smilax rotundifolia), and Poison Ivy (Rhus radicans).

Parent Material: Serpentinite residuum.

Physiography: Piedmont upland.

Slope: 3%, northeastern aspect.

Elevation: 210 meters.

Drainage: Somewhat poor to moderately well.

Erosion: None to slight.

Permeability: Slow.

Groundwater: Perched water table at 65 cm.

Described by: M. C. Rabenhorst and M. S. Patterson.

Date: 11/12/76.

Remarks: This profile does not fit the modal concept of the Chrome series because: 1) fine silty rather than fine particle size class (< 35% clay in the argillic horizon); and 2) serpentinitic rather than mixed mineralogy.

Profile 4
Chrome silt loam
S 76 Md 12-1
Lithic Hapludalf - fine loamy, serpentinic, mesic

| Horizon | Depth cm | Description |
|---|---|---|
| 01 | 4-0 | Pine needles and leaf litter. |
| A1 | 0-2 | Very dark gray (10YR 3/1) silt loam; moderate medium granular structure; very friable; roots abundant; extremely acid; abrupt smooth boundary. |
| A2 | 2-18 | Dark grayish brown (10YR 4/2) silt loam; weak fine to medium platy structure; friable; roots common; medium acid; clear smooth boundary. |
| B1 | 18-26 | Yellowish brown (10YR 5/4) silt loam; weak medium subangular blocky structure; friable; few roots; slightly acid; clear smooth boundary. |
| B2t | 26-43 | Yellowish brown (10YR 5/6) heavy silt loam; faint mottling in the lowest 1 to 2 cm of the horizon; moderate medium subangular blocky structure; friable; thin discontinuous clay films on ped faces; few roots; neutral; abrupt smooth boundary. |
| R | 43+ | Serpentinite bedrock. |

Location: Harford County, Maryland; Camp Oest, Broad Creek Scout Reservation, just east of the road to the reservoir.

Vegetation: Mixed woodland; mainly Virginia Pine (Pinus virginiana), various Oaks (Quercus sp.), and Greenbriar (Smilax rotundifolia).

Parent Material: Serpentinite residuum.

Physiography: Piedmont upland sideslope.

Slope: 5%, northern aspect.

| | |
|---|---|
| Elevation: | 95 meters. |
| Drainage: | Well. |
| Erosion: | Slight. |
| Permeability: | Moderate. |
| Groundwater: | Deeper than 43 cm. |
| Described by: | M. C. Rabenhorst and J. E. Foss. |
| Date: | 11/17/76 |
| Remarks: | This profile does not fit the modal concept of the Chrome series because: 1) shallowness to bedrock; 2) fine loamy rather than fine particle size class; and 3) serpentinitic rather than mixed mineralogy. |

Profile 5
Kelly silt loam
S 77 Md 12-1
Aquic Fragiudalf - fine silty, mixed, mesic.

| Horizon | Depth cm | Description |
|---|---|---|
| 01 | 3-0 | Oak leaves. |
| A1 | 0-6 | Dark grayish brown (10YR 4/2) silt loam; weak medium granular structure; very friable; roots abundant; extremely acid; clear smooth boundary. |
| A2 | 6-16 | Light olive brown (2.5Y 5/3) silt loam; weak medium subangular blocky structure; friable; roots common; very strongly acid; clear smooth boundary. |
| B1 | 16-32 | Light olive brown (2.5Y 5/4) silt loam; common fine distinct yellowish brown (10YR 5/6) mottles; moderate medium subangular blocky structure; friable; roots common; very strongly acid; clear smooth boundary. |
| B21t | 32-55 | Yellowish brown (10YR 5/8) silty clay loam; many medium prominent light brownish gray (2.5Y 6/2) mottles; moderate medium subangular blocky structure breaking to moderate medium plates; friable; few roots; thin clay films on ped faces; very strongly acid; gradual smooth boundary. |
| B22tx | 55-95 | Yellowish brown (10YR 5/6) silt loam; common medium prominent light brownish gray (2.5Y 6/3) and grayish brown (2.5Y 5/2 - on prism faces) mottles; very coarse prismatic structure breaking to medium to coarse plates; firm; few roots present only along prism faces; thick clay films on prism faces; very strongly acid; clear smooth boundary. |
| IIB3 | 95-110 | Light olive brown (2.5Y 5/4) loam; common medium prominent strong brown (7.5YR 5/6) mottles; structureless massive; very friable; medium acid. |
| IIC1 | 110-155 | Light olive brown (2.5Y 5/6) sandy loam; slightly acid. |

| Horizon | Depth cm | Description |
|---|---|---|
| IIC2 | 155-175 | Olive (5Y 5/6) sandy loam; neutral. |
| IIC3 | 175-205 | Light olive brown (2.5Y 5/6) sandy loam; neutral. |

Location: Harford County, Maryland; off Thomas Run Rd., 1/3 mile north of intersection with Prospect Mill Rd., 30 yards east of road in a wooded area; across from the Whittington house.

Vegetation: Mixed deciduous hardwood forest with White Oak (*Quercus alba*), Black Oak (*Quercus velutina*), and Red Maple (*Acer rubrum*).

Parent Material: Loess over metagabbro residuum.

Physiography: Gently undulating piedmont upland.

Slope: 4%, northern aspect.

Elevation: 115 meters.

Drainage: Somewhat poor.

Erosion: None to slight.

Permeability: Slow.

Groundwater: Deeper than 205 cm.

Described by: M. C. Rabenhorst.

Date: 5/17/77

Remarks: This profile does not fit the modal concept of the Kelly series because: 1) presence of a fragipan; and 2) fine silty rather than fine particle size class.

Profile 6
Aldino silt loam
S 77 Md 12-2
Typic Hapludalf - fine, mixed, mesic

| Horizon | Depth cm | Description |
|---|---|---|
| Ap | 0-18 | Yellowish brown (10YR 5/4) silt loam; weak fine subangular blocky and granular structure; very friable; roots common; slightly acid; abrupt smooth boundary. |
| B21t | 18-55 | Strong brown (7.5YR 5/6) silty clay; strong fine subangular blocky structure; friable; few roots; thin clay films on ped faces; very strongly acid; clear smooth boundary. |
| B22t | 55-78 | Yellowish brown (10YR 5/6) clay; common fine faint (10YR 6/4) and few fine prominent red (2.5YR 4/6) mottles; strong medium subangular blocky structure; firm; few roots; thin continuous clay films on ped faces; very strongly acid; clear smooth boundary. |
| B23t | 78-103 | Yellowish brown (10YR 5/6) clay; many coarse distinct light gray (2.5Y 6/1) and few fine prominent red (2.5YR 4/6) mottles; strong medium prismatic structure in upper portion grading into moderate medium subangular blocky structure in the lower portion; firm; few roots; thin continuous clay films on ped faces; very strongly acid; clear smooth boundary. |
| B3 | 103-158 | Yellowish brown (10YR 5/8) clay loam; many medium prominent pale olive (5Y 6/3), light olive gray (5Y 6/2), and strong brown (7.5YR 5/8) mottles; weak medium subangular blocky structure; friable; thin discontinuous clay films on ped faces; very strongly acid. |
| C1 | 158-236 | Pale yellow (5Y 7/4) loam; many medium prominent yellowish brown (10YR 5/8), yellow (10YR 7/8), and strong brown (7.5 YR 5/8) and few fine distinct gray (5Y 5/1) mottles; very strongly acid. |
| C2 | 236-260 | Olive yellow (5Y 6/6) sandy loam; many medium prominent strong brown (7.5YR 5/8) and yellow (10YR 7/8) mottles; strongly acid. |

| Horizon | Depth cm | Description |
|---|---|---|
| C3 | 260-310 | Light yellowish brown (2.5Y 6/4) sandy loam; common medium distinct yellowish brown (10YR 5/8 ) and pale yellow (2.5Y 7/4) mottles; strongly acid. |
| C4 | 310-371 | Pale olive (5Y 6/4) sandy loam; common medium prominent yellowish brown (10YR 5/8), white (10YR 8/1), and black (10YR 2.5/1) mottles; strongly acid. |
| C5 | 371-383 | Olive (5Y 5/4) sandy loam; many medium prominent brown (7.5YR 5/4) and reddish yellow (7.5YR 6/8) mottles; strongly acid. |
| C6 | 383-430 | Dark greenish gray (5GY 5/2) sandy loam; common medium prominent pale yellow (5Y 7/4) and strong brown (7.5YR 5/6) mottles; medium acid. |

Location: Harford County, Maryland; ¼ mile south of Aldino on Aldino-Stephany Rd., 40 yards west of the road in an open field.

Vegetation: Bluegrass turf (Poa pratensis).

Parent Material: Amphibolite residuum.

Physiography: Nearly level piedmont upland.

Slope: 1%, eastern aspect.

Elevation: 120 meters.

Drainage: Moderately well.

Erosion: Slight.

Permeability: Slow.

Groundwater: Water table at 310 cm.

Described by: M. C. Rabenhorst and J. E. Foss.

Date: 5/20/77

Remarks: This profile does not fit the modal concept of the Aldino series because: 1) absence of a fragipan; 2) fine rather than fine silty particle size class; and 3) very deep to bedrock.

Profile 7
Chrome silt loam
S 77 Md 7-1
Typic Hapludalf - fine loamy, serpentinitic, mesic

| Horizon | Depth cm | Description |
|---|---|---|
| 01 | 3-0 | Oak leaves and pine needles. |
| A1 | 0-3 | Dark brown (10YR 4/3) silt loam; weak fine granular structure; very friable; roots abundant; extremely acid; clear smooth boundary. |
| B1 | 3-27 | Dark yellowish brown (10YR 4/4) silt loam; weak medium subangular blocky structure; very friable; roots common; strongly acid; clear smooth boundary. |
| B21t | 27-43 | Dark yellowish brown (10YR 4/4) silt loam; moderate medium subangular blocky structure; friable; roots common; thin discontinuous clay films on ped faces; slightly acid; clear smooth boundary. |
| B22t | 43-92 | Dark yellowish brown (10YR 4/4) silt loam; common medium distinct strong brown (7.5YR 5/6) and brown (10YR 5/3) mottles; weak medium subangular blocky structure; friable; few roots; thin discontinuous clay films on ped faces; many rock fragments present; slightly acid; gradual wavy boundary. |
| B3 | 92-104 | Dark yellowish brown (10YR 4/4) angular cobbly silt loam; common medium distinct strong brown (7.5YR 5/6) and brown (10YR 5/3) mottles; neutral. |
| R | 104+ | Serpentinite bedrock with chlorite veins. |

Location: Cecil County, Maryland; on Rock Springs Rd., ½ mile west of the intersection with Md. Rt. 222, 20 yards on north side of road in the woods.

Vegetation: Mixed stunted forest of Virginia Pine (Pinus virginiana), Blackjack Oak (Quercus marilandica), and Greenbriar (Smilax rotundifolia).

| | |
|---|---|
| Parent Material: | Serpentinite residuum. |
| Physiography: | Nearly level piedmont upland. |
| Slope: | 1%, southern aspect. |
| Elevation: | 135 meters. |
| Drainage: | Moderately well. |
| Erosion: | None to slight. |
| Permeability: | Moderate. |
| Groundwater: | Deeper than 104 cm. |
| Described by: | M. C. Rabenhorst. |
| Date: | 5/26/77 |
| Remarks: | This profile does not fit the modal concept of the Chrome series because: 1) fine loamy rather than fine particle size class; and 2) serpentinitic rather than mixed mineralogy. |

The maximum depth of sampling in profile 3 is considerably greater than the other serpentine soils studied. While not conclusive in themselves, this greater depth as well as silty textures, may suggest that eolian additions have occurred at this site. Some Maryland workers have already suggested that the greater depth of some serpentine soils in Harford County may be due to loess additions (Smith & Matthews, 1975).

Seismographic determinations were made at several of the sampling sites. An attempt was made to correlate the characteristics observed during sampling with the discontinuities noted and measured using a portable seismographic unit. Figure 3 shows the velocities of sound waves moving through various layers of material in the geologic column at three sampling sites. Steeper slopes indicate lower velocities and slope breaks indicate discontinuities in the profile. The points represent measurements made during the determinations. Calculations were made to determine the depths at which the discontinuities occur.

At the sites of profiles 5 and 6, straight line graphs were easily fit to the data points indicating, in these cases, three fairly distinct layers of material with depth. In profile 5, the discontinuity at 93 cm correlated very well with the boundary between residual material and an overlying silty mantle. The discontinuity at 393 cm probably represents the transition from saprolite into hard bedrock. According to the interpretation manual provided with the seismograph,

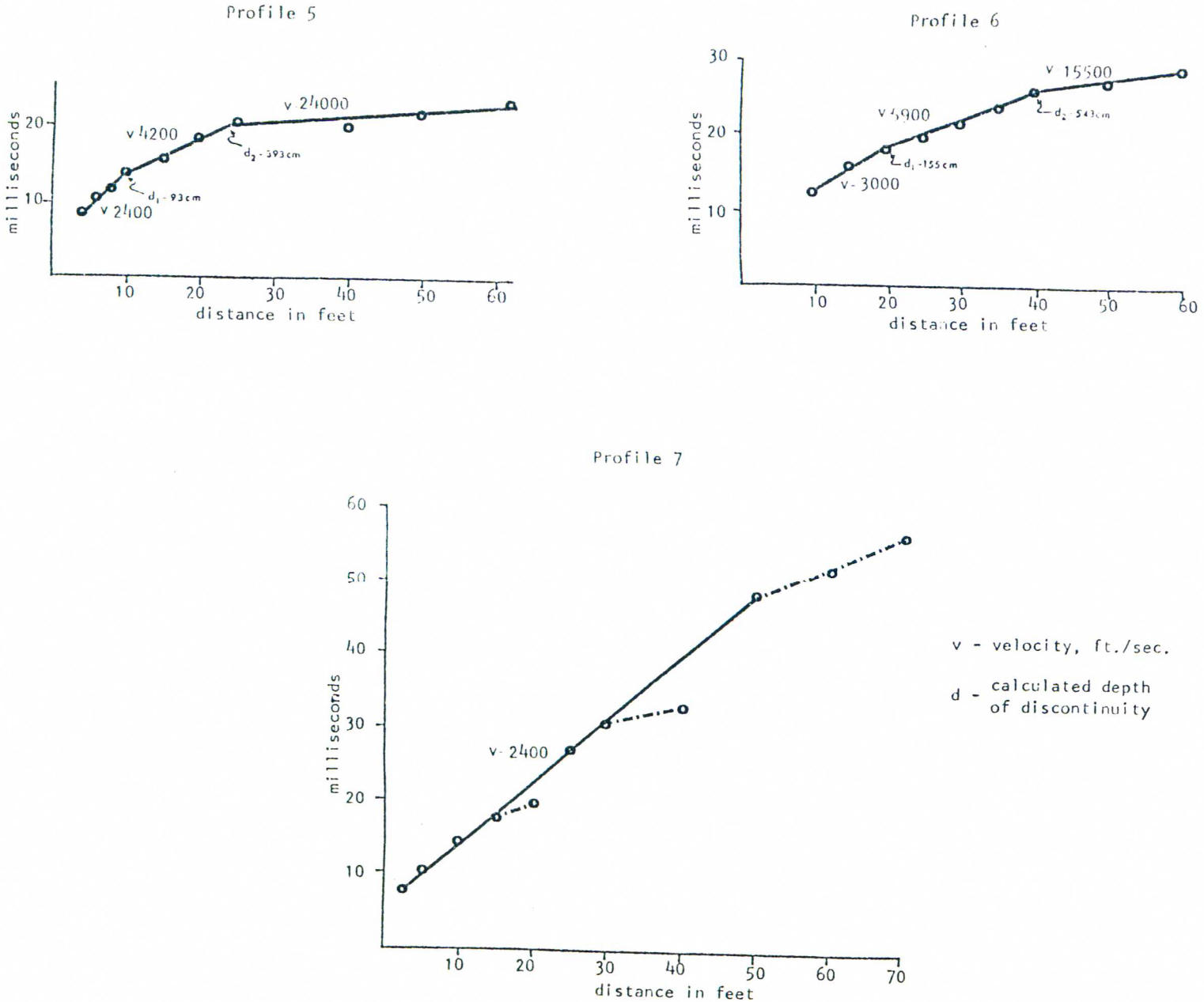



Figure 3. Velocity of sound waves through soil and rock measured along seismographic transects at three profile locations.

sound waves moving at a velocity greater than about 10,000 to 15,000 ft. per second are probably traveling through consolidated rock. The velocity in the uppermost portion of the graph for profile 5 is considerably greater than this, suggesting that the waves are moving through a very hard, dense rock. Velocities below 10,000 ft. per second indicate that the material is either fractured, less dense, or unconsolidated. The inability to sample below a depth of 205 cm was probably due to the presence of coarse fragments in the C horizon material which obstructed sampling with a bucket auger, thus showing one of the limitations of this sampling procedure.

In profile 6, the discontinuity at 155 cm correlated well with the transition from the solum to the saprolite. The discontinuity at 543 cm probably marks the boundary between saprolite and bedrock. In this instance, sampling was limited to a depth of 430 cm by a lack of handle extensions for the auger, rather than by encountering rock. This would explain the discrepancy between the maximum depth of sampling and the depth to bedrock measured using the seismograph.

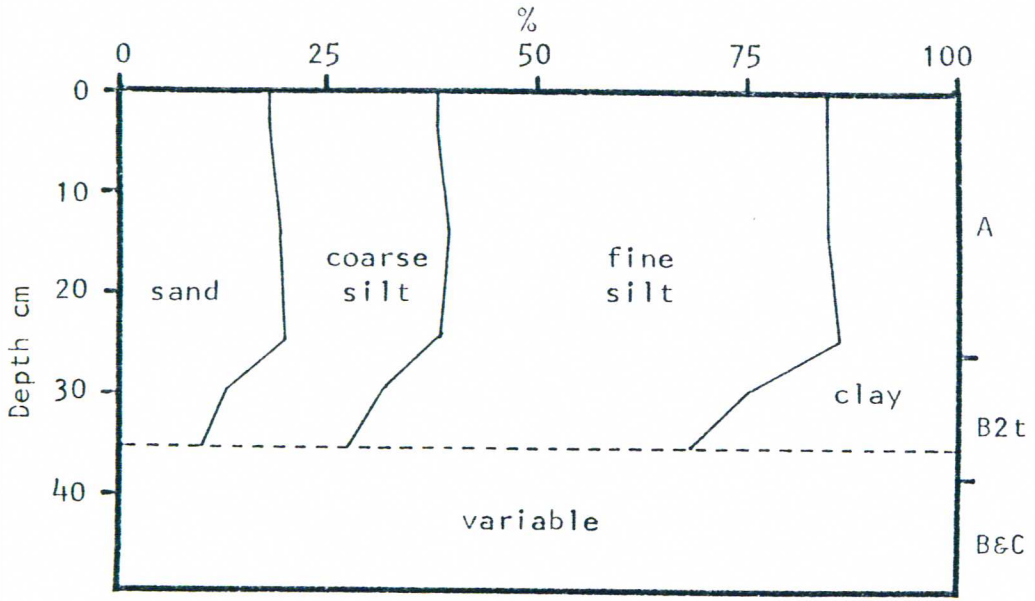
In the case of profile 7, a series of straight line graphs do not easily fit the data points. This may indicate some irregularity in the soil column along the seismographic transect such as boulders or shattered rock at various positions in the profile. If the obstruction is either unique or directional, an alternate transect may be run at an angle perpendicular to the first. In this manner, interference

encountered in the first transect might be avoided in the second. In cases where obstructions or irregularities are non-directional, no simple solution is apparent.

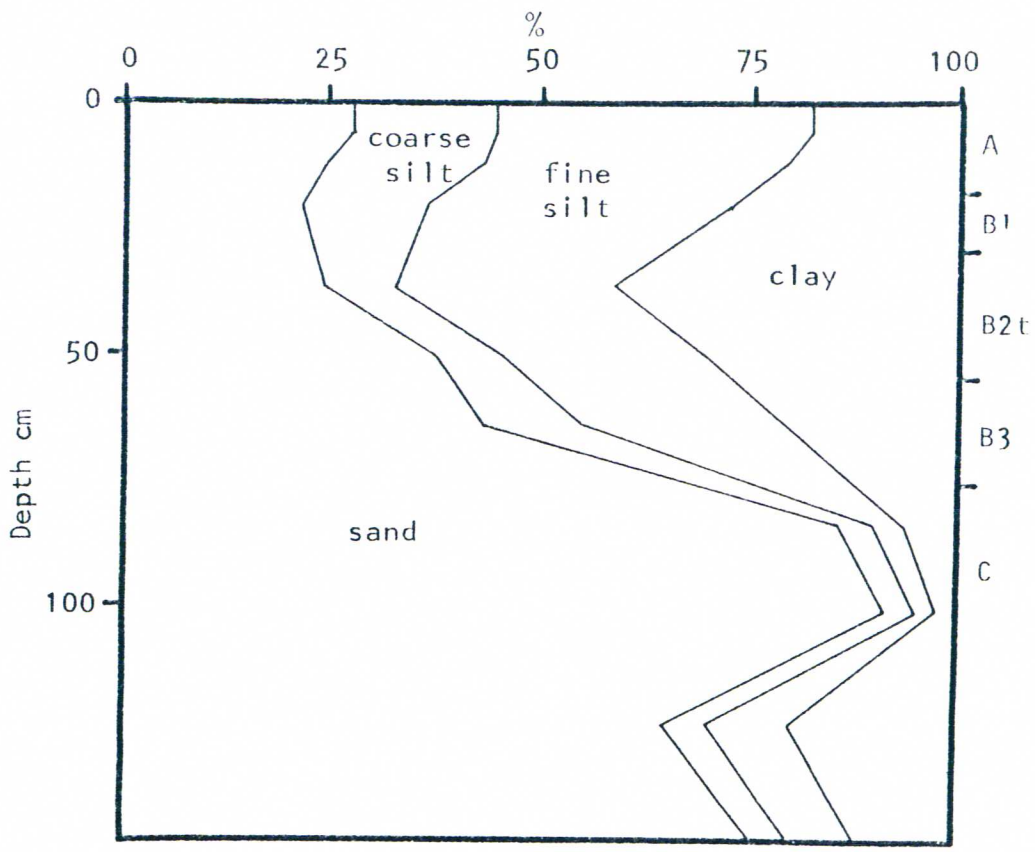
Particle Size

Particle size data for all seven profiles are presented in Figure 4. The cumulative percentages of sand, coarse and fine silt, and clay are plotted with depth. Complete particle size data can be found in Appendix A. The silt fraction dominates the particle size distribution in the upper portion of all the profiles. In those profiles which have formed from serpentinite (1, 3, 4, and 7), the silt fraction remains dominant to the base of the profile. The lower horizons of the non-serpentine soils, however, are dominated by the sand fraction. The lesser amounts of sand in the lower horizons of serpentine soils is probably related to the general absence of saprolite in these soils as reported by Cleaves et al. (1974).

This contrast in particle size in the lower horizons of soils formed from these two parent materials, may be due in part to the grain size of the parent rock. In examining some California soils formed from various parent materials, Harradine and Jenny (1958) stated that the fabric or grain size as well as the chemical content of the parent rocks affect the weathering products. Their work showed that the soils formed from aphanitic basalts were fine textured while those formed from phaneritic granodiorites were more sandy.

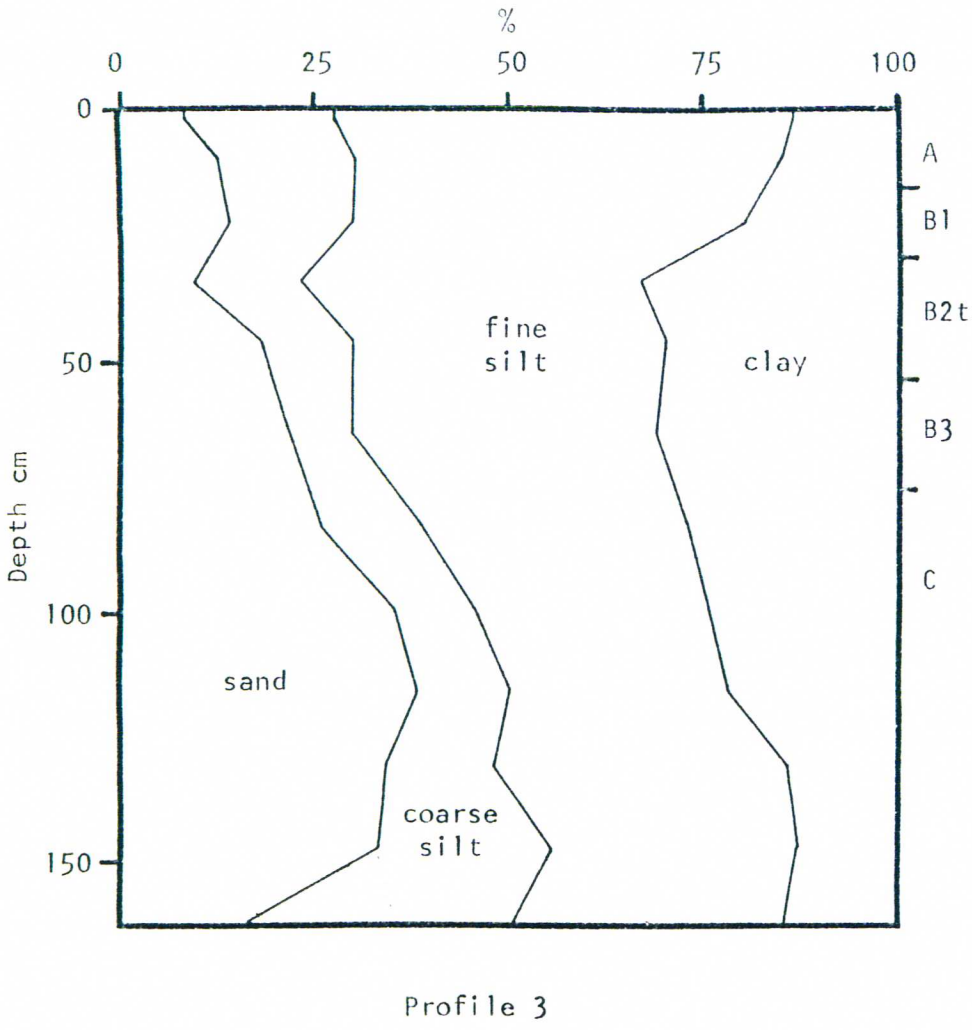



Profile 1

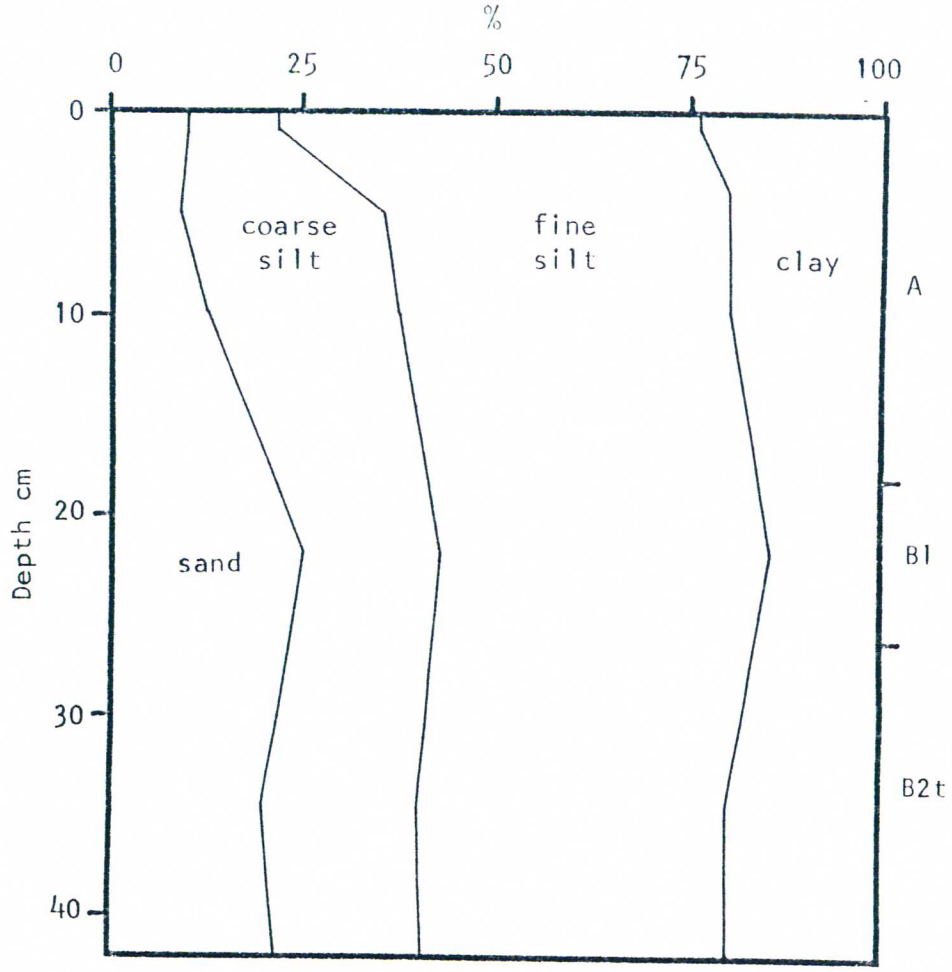



Profile 2

Figure 4. Particle size distribution with depth for the seven profiles studied.

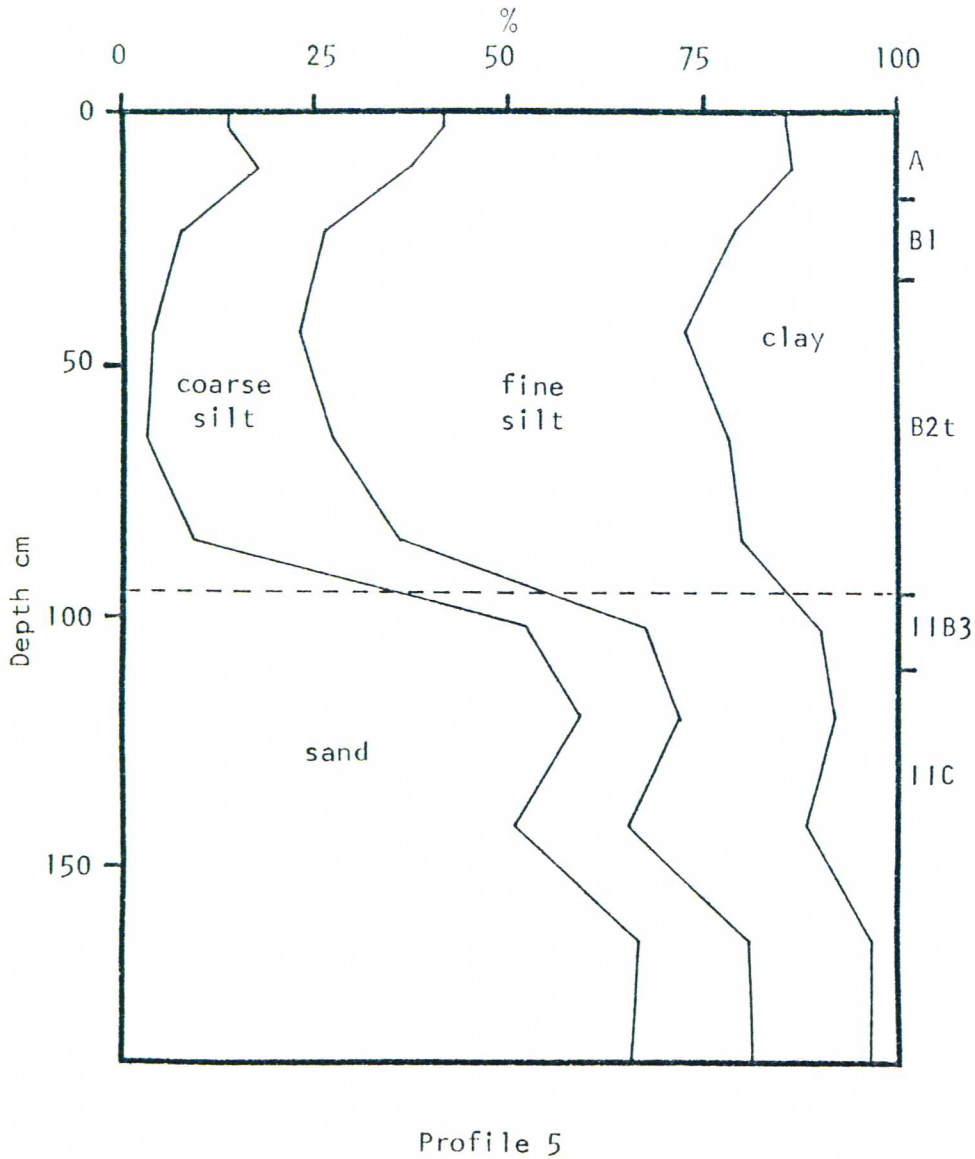



Profile 3




Profile 4

Figure 4. (continued)



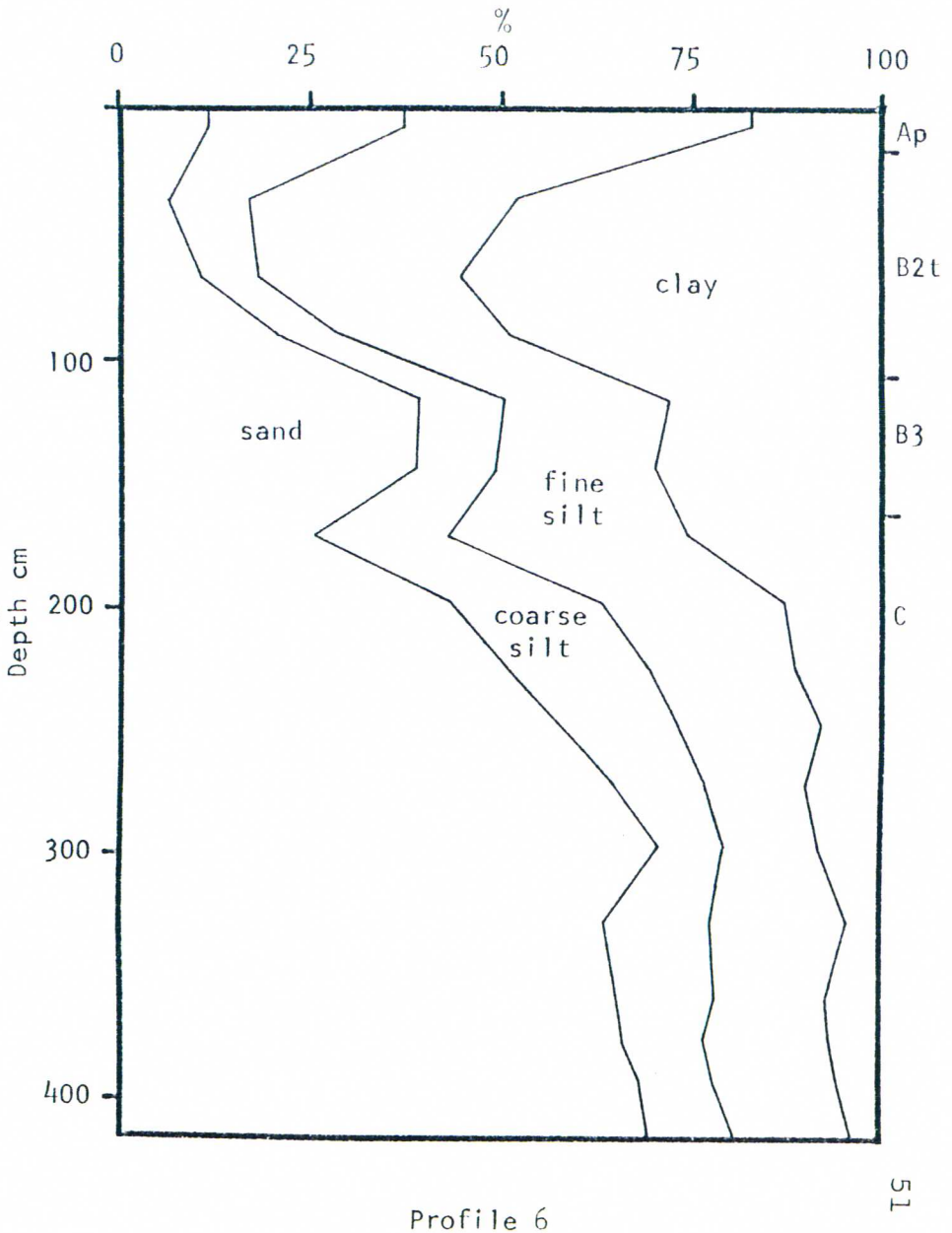
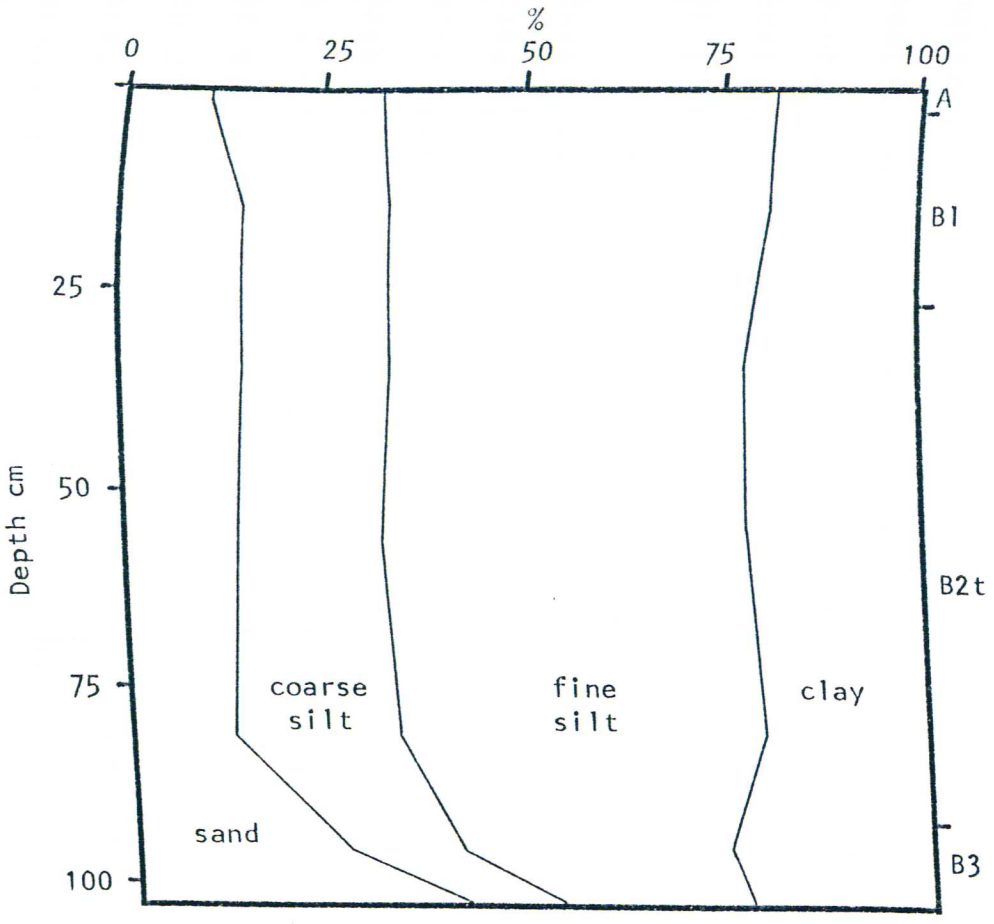




Figure 4. (continued)




Profile 7

Figure 4. (continued)

Being an aphanitic rock, serpentinite does not lend itself as easily to the formation of coarse grained particles by disintegration processes as does coarser textured rock. While mafic rocks may be either coarse or fine textured, the parent materials of profiles 2, 5, and 6 were all phaneritic. Initial weathering and disintegration of the coarse grained rocks would probably result in coarser material nearer the rock soil interface. Continued weathering would cause a further reduction in particle size nearer to the soil surface.

In profile 5, the extreme change in particle size between the B2 and IIB3 horizons is due to a lithologic discontinuity. This is believed to be an instance of loess deposition over metagabbro residuum, which would account for the high levels of silt to a depth of nearly one meter. Foss et al. (1978) have reported loess deposits on the eastern shore of Maryland between 30 and 147 cm thick and at distances up to 25 km from the Chesapeake Bay, which they cite as the source area. Other workers have reported loess deposits nearby in southeastern Pennsylvania and in New Jersey (Carey et al., 1976; Tedrow & MacClintock, 1953). The site of profile 5 is approximately 14 km northwest of Bush River, a tributary of the Chesapeake Bay, and about 18 km from the Bay itself, which is within the distance that loess was reported by Foss et al. (1978).

Using the method described by Folk and Ward (1957) median and mean particle diameters and graphic standard

deviation were calculated for samples of profile 5. Sorting coefficients were calculated by the method of Trask (1932). Data are presented in Table 1. The graphic standard deviation is another measure of the degree of sorting in the material and is given in Ø units which are logarithmic transformations of the Wentworth particle size system. The median and mean particle diameters for the samples taken above 95 cm fall into the fine silt category, and although somewhat smaller, are comparable to the median values reported by Carey et al. (1976). The graphic standard deviations of this silty material are in the very poorly sorted category of Folk and Ward (1957), but according to the classification used by Carey et al. (1976), the sorting coefficients are in the moderately well sorted category, and are comparable to the values reported for loess by these workers. Graphic standard deviations and sorting coefficients sharply increase for the underlying residual material indicating a difference in origin.

Although weakly expressed in profiles 4 and 7, an increase in clay content in the B horizons has been observed in all seven profiles. This increase in clay has also been accompanied by evidence of translocation such as oriented clay films, resulting in the recognition of argillic horizons in all of the profiles described.

Table 2 shows the percentage clay in the eluvial and illuvial horizons, the difference in percent clay, and the ratio of percent clay between the two horizons. As previously

Table 1. Mean and median particle diameters and sorting values for samples from Profile 5.

| Lab No. | Depth cm. | Horizon | Median | Mean | Graphic S.D. | Sorting Coef. |
|---|---|---|---|---|---|---|
| | | | ------μm----- | | | |
| 6238 | 0-6 | A1 | 14.3 | 11.5 | 2.59 | 2.83 |
| 6239 | 6-16 | A2 | 11.8 | 12.1 | 2.79 | 2.98 |
| 6240 | 16-32 | B1 | 7.3 | 7.0 | 2.08 | 2.93 |
| 6241 | 32-55 | B21t | 5.5 | 5.2 | 2.26 | 3.19 |
| 6242 | 55-75 | B22tx | 7.3 | 6.3 | 2.12 | 3.05 |
| 6243 | 75-95 | | 10.0 | 8.0 | 2.37 | 3.22 |
| 6244 | 95-110 | IIB3 | 56.3 | 48.5 | 3.40 | 4.84 |
| 6245 | 110-130 | IIC1 | 85.4 | 69.3 | 3.58 | 6.00 |

Table 2. Parameters for determining degree of expression of argillic horizons in the soils studied.

| Profile | Parent Material | (E) Eluvial Horizon % clay | (I) Illuvial Horizon % clay | I-E | I:E |
|---|---|---|---|---|---|
| 1 | Serpentinite | 14.6 | 31.8 | 17.2 | 2.18 |
| 2 | Diabase | 17.8 | 41.4 | 23.6 | 2.33 |
| 3 | Serpentinite | 13.2 | 32.8 | 19.6 | 2.48 |
| 4 | Serpentinite | 14.4 | 20.2 | 5.8 | 1.40 |
| 5 | Loess over Metagabbro | 13.6 | 27.4 | 13.8 | 2.01 |
| 6 | Amphibolite | 17.5 | 55.7 | 38.2 | 3.18 |
| 7 | Serpentinite | 17.9 | 25.9 | 8.0 | 1.45 |

mentioned, serpentine profiles 4 and 7 show the weakest development of the argillic horizon. The most marked expression of the argillic horizons occurs in the two profiles in which the sola have developed from non-serpentine mafic residuum, while the remaining profiles show moderate development and expression of the argillic horizon. Since the argillic horizons in profiles 4 and 7 are less strongly expressed, either: 1) the processes of eluviation and illuviation have not been acting on these soils as long as on those soils with stronger development; 2) the landscape conditions have been such that processes of denudation have prevented further expression of the argillic horizon; 3) the parent material is less subject to those processes which form the argillic.

Profile 5, which has formed in loess shows a clay increase in the B2t horizon which is comparable to data reported by Foss (1974) and Foss and Rust (1968). This suggests that the loess in profile 5 may have been deposited toward the end of the Wisconsin stage. Similar conclusions have been made about the age of loess deposits in Pennsylvania and New Jersey (Carey et al., 1976; Tedrow & MacClintock, 1953).

The clay maxima for the two soils formed from non-serpentine mafic residuum are considerably greater than those of other profiles. This may be a reflection of a longer period of pedogenesis or of different susceptibilities of the parent material to weathering and clay formation. While there is evidence of illuviation of clay, some of the clay is probably

present as the result of weathering and formation *in situ* as was reported by Smeck et al. (1968) for some soils in Ohio.

Examination of the distribution of sand fractions with depth has been shown to be a useful tool in identifying lithologic discontinuities in soil profiles (Foss, 1974). The distributions of sand fractions for the seven profiles studied are presented in Figure 5. In profile 5, the levels of all sand fractions show a rapid increase between 90 and 100 cm. As has been previously suggested, a lithologic discontinuity is probably present at this depth in the profile. The elemental analyses of the silt fractions further substantiate the identification of a discontinuity in profile 5 by showing large changes in the elemental distribution within a narrow depth increment.

While the discontinuity in profile 5 was identified on the basis of particle size data, this information is not always sufficient for positive identification. This is illustrated in profile 2, which, as a result of the large increase in percent sand and a disproportionately large increase in coarse and very coarse sand, might be suspected of having a discontinuity at approximately 75 cm. Data for the elemental analyses of silts, however, show fairly gentle trends across this depth rather than a more drastic variation, which would be expected if there were in fact a discontinuity present.

In profiles 1, 3, and 7 the very coarse and coarse sand fractions are dominant, even in the upper portions of

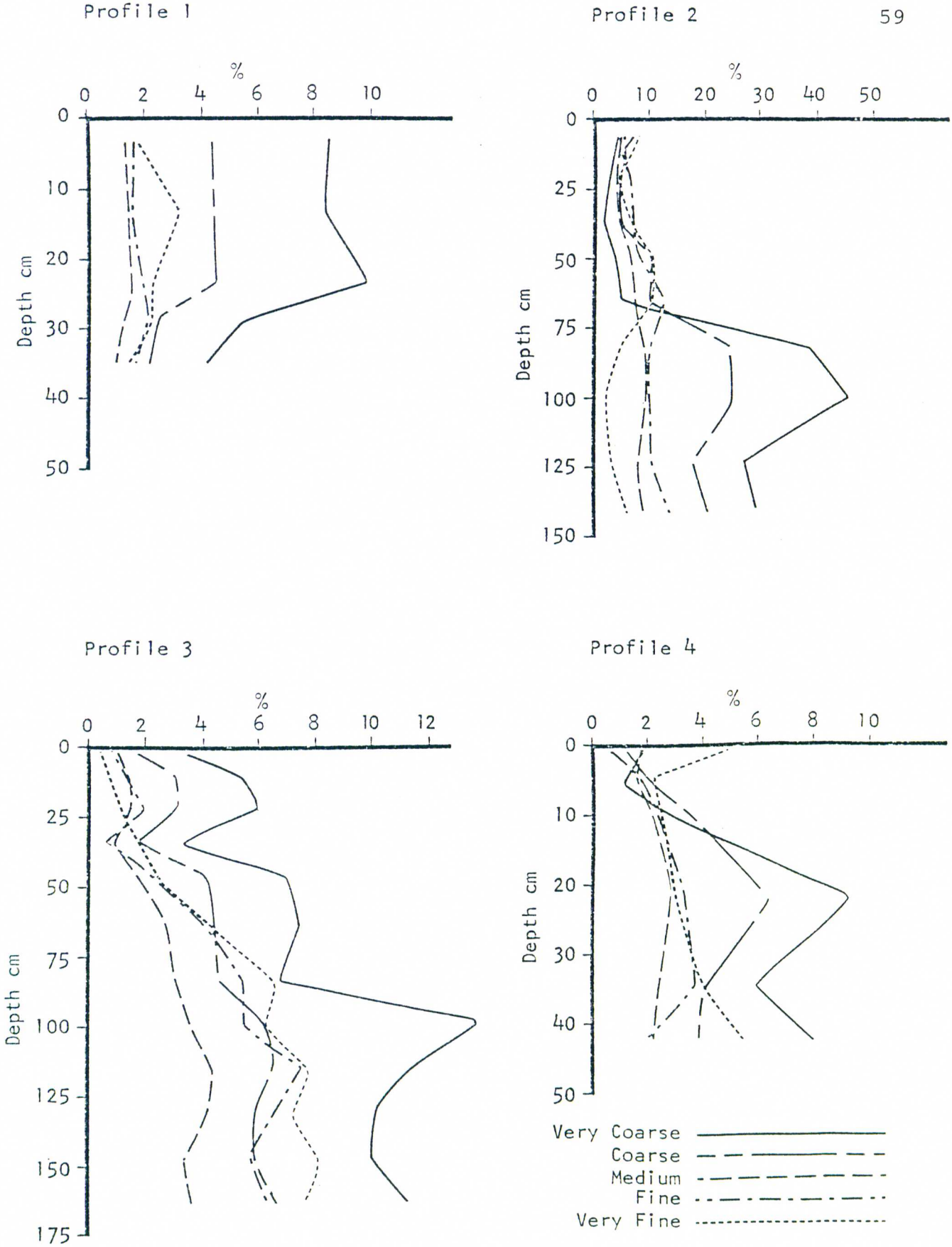



Figure 5. Distribution of sand fractions with depth in the seven study profiles.

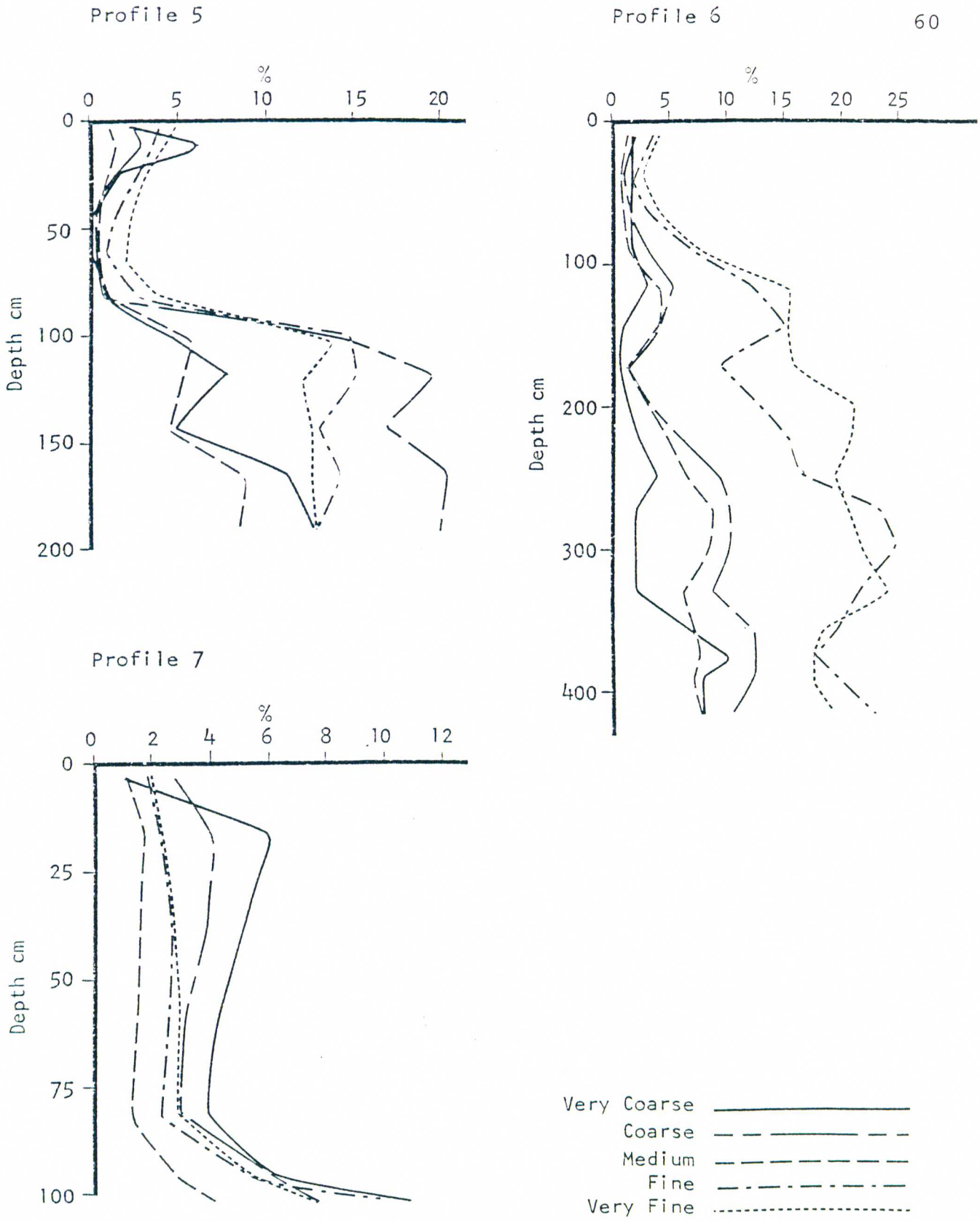



Figure 5. (continued)

the profile. Profile 5, which has formed in loess, also shows as much as 4 to 8 percent coarse and very coarse sand in the upper portion. Since very coarse and coarse sand is generally not expected to occur in loess, another explanation is necessary. Examination of the sands has revealed that all of the very coarse and coarse sand and much of the medium sand in the upper horizons of the profiles mentioned above, are comprised of ferromanganiferous concretions.

Data in Table 3 show the occurrence of iron-manganese concretions in the profiles studied. Visual estimates of the percent concretions were made for the sand fraction of each horizon using a scale from 0 to 5. Most reports of iron-manganese concretions have related their occurrence and formation to impeded drainage and have indicated that the concretions were most abundant in the A and B horizons (Cescas et al., 1970; Drosdoff & Nikiforoff, 1940; Pawluk & Dumanski, 1973; Phillippe et al., 1972; Schwertmann & Fanning, 1976; Wheeting, 1936; Winters, 1938). Concretions in these soils appear to be most prevalent in the upper 50 cm of the profile. The fairly high levels of structural Fe and the occurrence of restricted drainage in nearly all of the profiles, may explain the presence of iron-manganese concretions in these soils.

## Potential Volume Change

The measurement of potential volume change (PVC) was made on the B2t horizons of all profiles, and in some instances the B3 or C horizons. The results of these determinations are

Table 3. Estimate of concretions in the sand fraction and whole soil for the profiles studied.

| Depth cm | Concretion Estimate * | % Total Sand | Approx. % Concretions in Soil |
|---|---|---|---|
| **Profile 1** | | | |
| 0-6 | 4 | 18.0 | 15 |
| 6-21 | 4 | 18.9 | 15 |
| 21-26 | 4 | 20.0 | 15 |
| 26-32 | 4 | 13.1 | 10 |
| 32-38 | 4 | 10.1 | 5 |
| 38-60 (si) | 4 | 13.4 | 10 |
| 38-60 (c) | 4 | 17.7 | 10 |
| 38-60 (g) | 5 | 45.3 | 40 |
| **Profile 2** | | | |
| 0-11 | 3 | 27.3 | 15 |
| 11-13 | 3 | 23.9 | 10 |
| 13-29 | 2 | 21.6 | 5 |
| 29-45 | 1 | 24.1 | tr |
| 45-54 | 1 | 33.7 | 5 |
| 54-75 | 1 | 43.1 | 5 |
| 75-92 | 0 | 86.0 | 0 |
| 92-110 | 0 | 91.6 | 0 |
| 110-138 | 0 | 65.4 | 0 |
| 138-154 | 0 | 75.8 | 0 |
| **Profile 3** | | | |
| 0-4 | 2 | 8.5 | 5 |
| 4-16 | 4 | 12.6 | 10 |
| 16-28 | 4 | 14.1 | 10 |
| 28-40 | 3 | 9.4 | 5 |
| 40-53 | 3 | 18.1 | 10 |
| 53-75 | 1 | 21.9 | 0 |
| 75-91 | 0 | 26.3 | 0 |
| 91-107 | 0 | 35.6 | 0 |
| 107-123 | 0 | 38.0 | 0 |
| 123-139 | 0 | 34.2 | 0 |
| 139-155 | 0 | 33.0 | 0 |
| 155-170 | 0 | 15.7 | 0 |
| **Profile 4** | | | |
| 0-2 | 1 | 10.3 | tr |
| 2-8 | 2 | 8.9 | 5 |
| 2-18 | 3 | 12.7 | 5 |
| 18-26 | 2 | 25.1 | 10 |
| 26-43 | 1 | 19.8 | tr |
| 41-43 | 0 | 21.9 | 0 |

Table 3. (continued)

| Depth cm | Concretion Estimate* | % Total Sand | Approx. % Concretions in Soil |
|---|---|---|---|
| Profile 5 | | | |
| 0-6 | 3 | 13.9 | 5 |
| 6-16 | 4 | 17.8 | 10 |
| 16-32 | 3 | 8.4 | 5 |
| 32-55 | 1 | 3.8 | tr |
| 55-75 | 1 | 3.5 | tr |
| 75-95 | 0 | 8.9 | 0 |
| 95-110 | 0 | 51.9 | 0 |
| 110-130 | 0 | 58.9 | 0 |
| 130-155 | 0 | 51.9 | 0 |
| 155-175 | 0 | 66.9 | 0 |
| 175-205 | 0 | 65.8 | 0 |
| Profile 6 | | | |
| 0-18 | 1 | 11.4 | tr |
| 18-55 | 2 | 7.1 | tr |
| 55-78 | 1 | 11.2 | tr |
| 78-103 | 1 | 20.5 | tr |
| 103-130 | 0 | 39.0 | 0 |
| Profile 6 (continued) | | | |
| 130-158 | 0 | 38.8 | 0 |
| 158-183 | 0 | 25.2 | 0 |
| 183-211 | 0 | 43.4 | 0 |
| 211-236 | 0 | 50.4 | 0 |
| 236-260 | 0 | 57.8 | 0 |
| 260-285 | 0 | 64.9 | 0 |
| 285-310 | 0 | 70.7 | 0 |
| 310-346 | 0 | 63.7 | 0 |
| 346-371 | 0 | 65.3 | 0 |
| 371-383 | 0 | 66.3 | 0 |
| 383-400 | 0 | 68.0 | 0 |
| 400-430 | 0 | 69.9 | 0 |
| Profile 7 | | | |
| 0-3 | 2 | 10.6 | 5 |
| 3-27 | 3 | 15.5 | 10 |
| 27-43 | 3 | 15.6 | 10 |
| 43-70 | 2 | 13.9 | 5 |
| 70-92 | 1 | 12.6 | r |
| 92-100 | 0 | 26.3 | 0 |
| 100-104 | 0 | 40.7 | 0 |

*5 80-100% of sand fraction
4 60-80%
3 40-60%
2 20-40% of sand fraction
1 0-20%
0 None

presented in Table 4. Wagner (1976) reported that Lower Cretaceous sediments which were higher in clay also had higher swell indicies. Figure 6, however, shows that there is a low correlation between PVC and clay levels in soils formed from mafic and ultramafic rocks.

Values for all four of the serpentine samples fall into the non-critical category of the Federal Housing Administration system thus indicating that these soils present no shrink-swell hazard to development. Sample 6242 from the upper portion of profile 5 which was developed in loess, also was classified as non-critical. The sample from the lower part of profile 5, as well as the other samples developed from mafic residuum, had swell indicies sufficiently high to be classified as marginal, critical or very critical, indicating that these soils present slight to severe shrink-swell hazards to development.

These data suggest that the mineralogy of these soils is the dominant factor affecting PVC. The relatively low clay percentage of sample 6255 and its extremely high swell index suggests the presence of expansible minerals in the silt and sand size fractions which greatly contributes to the PVC. Coffman and Fanning (1975) have previously reported the occurrence of silt and sand sized vermiculite in Maryland soils formed from chloritic metabasalt.

Table 4. Potential volume change for selected samples from the seven profiles studied.

| | Parent Material | Lab No. | Horizon | Depth cm | sand | % silt | clay | Swell Index lbs/ft$^2$ | PVC Rating |
|---|---|---|---|---|---|---|---|---|---|
| Profile 1 | Serpentinite | 6205 | B2t | 26-32 | 13.1 | 62.1 | 24.8 | 0 | non-critical |
| Profile 2 | Diabase | 6214 | B22t | 45-54 | 37.7 | 31.7 | 30.6 | 4,600 | critical |
| | Diabase | 6218 | C3 | 110-138 | 65.4 | 14.9 | 19.7 | 4,075 | critical |
| Profile 3 | Serpentinite | 6224 | B22t | 40-53 | 18.1 | 52.1 | 29.8 | 350 | non-critical |
| Profile 4 | Serpentinite | 6236 | B2t | 26-43 | 19.8 | 60.0 | 20.2 | 470 | non-critical |
| Profile 5 | Loess | 6242 | B22tx | 55-75 | 3.5 | 74.1 | 22.4 | 1,050 | non-critical |
| | Metagabbro | 6244 | IIB3 | 95-110 | 51.9 | 37.0 | 11.1 | 1,875 | marginal |
| Profile 6 | Amphibolite | 6251 | B22t | 55-78 | 11.2 | 33.1 | 55.7 | 6,800 | very critical |
| | Amphibolite | 6255 | C1 | 158-183 | 25.2 | 49.1 | 25.7 | 10,800 | very critical |
| Profile 7 | Serpentinite | 6269 | B22t | 43-70 | 13.9 | 63.7 | 22.4 | 700 | non-critical |

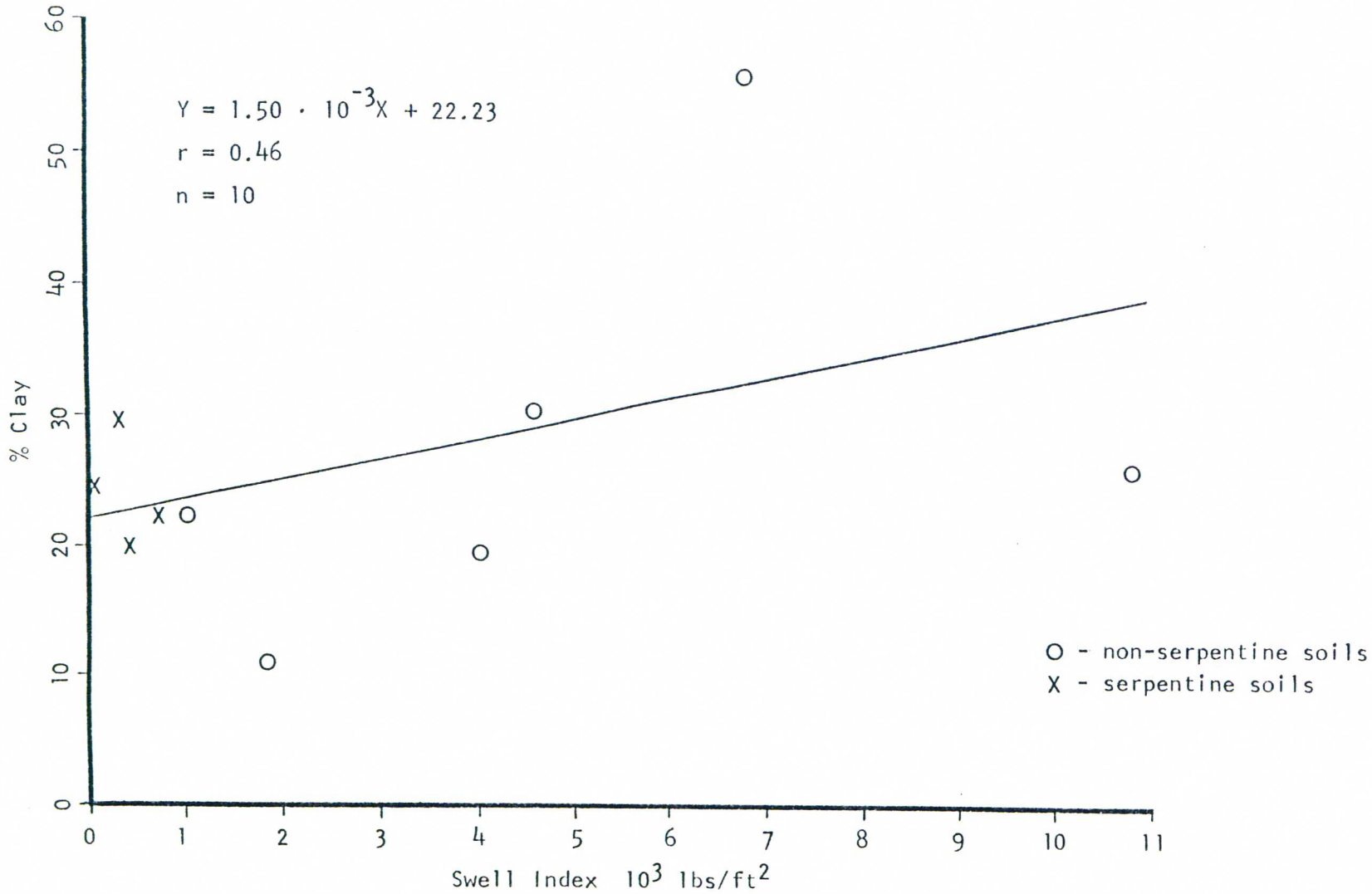



Figure 6. Potential volume change vs. percentage clay for samples from the B and C horizons of the seven profiles studied.

Extractable Nutrients

Data for extractable nutrients of the seven profiles described are presented in Table 5. Data for all other samples collected can be found in Appendix B. Extractable Mg levels were very high in virtually all of the profiles. The one exception was profile 5 where the upper horizons had developed in loess and thus were somewhat lower in Mg.

With the exception of the loess-derived horizons of profile 5, those soils formed from non-serpentinite mafic residuum demonstrated very high Ca levels ranging from 350 to 1100 ppm. Unlike serpentinite, the parent rock of these soils contains Ca in the form of plagioclase, hornblende and calcic pyroxenes. The weathering of these minerals in the process of pedogenesis releases Ca from the mineral structures to the soil.

The weathering of Ca-poor serpentinite has resulted in soils which are very low in extractable Ca. The only exceptions are the organic rich surface horizons of profiles 1, 3, and 4 which contain between 4.5 and 28 times more extractable Ca than the underlying horizons. The rather rapid decreases in Ca below the A1 horizon in these soils suggest that these higher levels are due to biologic recycling and surface additions of Ca-rich plant materials to the soil (Chandler, 1941; Nye, 1961; Ovington, 1965). An alternative explanation is the possible addition of wind-borne dust as described by Syers et al. (1969) which might be higher in Ca. The very rapid decrease in Ca levels rather than a gradual decrease due to mixing, however, casts doubt on this hypothesis.

Table 5. Extractable nutrient levels in the seven study profiles.

| Depth | Mg | P | K | Ca | Ca:Mg |
|---|---|---|---|---|---|
| | ppm | | | | |
| Profile 1 | | | | | |
| 0-6 | 402 | 2 | 37 | 545 | 1.35 |
| 6-21 | 272 | 2 | 16 | 240 | 0.88 |
| 21-26 | 315 | 2 | 14 | 100 | 0.32 |
| 26-32 | 540 | 2 | 24 | 120 | 0.22 |
| 32-38 | 618 | 2 | 31 | 105 | 0.17 |
| 38-60(si) | 592 | 2 | 29 | 65 | 0.11 |
| 38-60(c) | 702 | 2 | 40 | 60 | 0.09 |
| 38-60(g) | 530 | 2 | 22 | 70 | 0.13 |
| Profile 2 | | | | | |
| 0-11 | 408 | 2 | 31 | 395 | 0.97 |
| 11-13 | 470 | 2 | 22 | 510 | 1.09 |
| 13-29 | 528 | 2 | 26 | 695 | 1.32 |
| 29-45 | 640 | 2 | 31 | 810 | 1.27 |
| 45-54 | 622 | 4 | 37 | 905 | 1.45 |
| 54-75 | 702 | 8 | 40 | 975 | 1.39 |
| 75-92 | 430 | 19 | 17 | 590 | 1.74 |
| 92-110 | 335 | 26 | 11 | 465 | 1.39 |
| 110-138 | 468 | 14 | 29 | 1,100 | 2.35 |
| 138-154 | 535 | 22 | 25 | 1,030 | 1.93 |
| Profile 3 | | | | | |
| 0-4 | 460 | 2 | 60 | 1,125 | 2.45 |
| 4-16 | 410 | 2 | 19 | 115 | 0.39 |
| 16-28 | 522 | 2 | 27 | 45 | 0.09 |
| 28-40 | 642 | 2 | 43 | 40 | 0.06 |
| 40-53 | 638 | 2 | 41 | 45 | 0.07 |
| 53-75 | 605 | 3 | 38 | 45 | 0.07 |
| 75-91 | 608 | 3 | 44 | 60 | 0.10 |
| 91-107 | 582 | 3 | 46 | 65 | 0.11 |
| 107-123 | 602 | 3 | 38 | 65 | 0.11 |
| 123-139 | 510 | 2 | 28 | 85 | 0.17 |
| 139-155 | 455 | 2 | 26 | 70 | 0.15 |
| 155-170 | 492 | 3 | 29 | 70 | 0.14 |
| Profile 4 | | | | | |
| 0-2 | 570 | 3 | 92 | 770 | 1.35 |
| 2-8 | 452 | 2 | 24 | 30 | 0.07 |
| 2-18 | 464 | 2 | 20 | 40 | 0.09 |

Table 5. (continued)

| Depth | Mg | P | K | Ca | Ca:Mg |
|---|---|---|---|---|---|
| | ppm | | | | |
| Profile 4 (continued) | | | | | |
| 18-26 | 520 | 2 | 18 | 30 | 0.06 |
| 26-43 | 390 | 3 | 25 | 30 | 0.08 |
| 41-43 | 658 | 3 | 29 | 25 | 0.04 |
| Profile 5 | | | | | |
| 0-6 | 38 | 3 | 28 | 20 | 0.53 |
| 6-16 | 10 | 2 | 7 | 13 | 1.25 |
| 16-32 | 62 | 2 | 9 | 13 | 0.21 |
| 32-55 | 286 | 2 | 13 | 20 | 0.07 |
| 55-75 | 294 | 3 | 13 | 93 | 0.32 |
| 75-95 | 516 | 3 | 12 | 266 | 0.52 |
| 95-110 | 398 | 2 | 7 | 456 | 1.15 |
| 110-130 | 370 | 2 | 5 | 450 | 1.22 |
| 130-155 | 436 | 2 | 6 | 616 | 1.41 |
| 155-175 | 294 | 2 | 4 | 366 | 1.24 |
| 175-205 | 345 | 2 | 5 | 500 | 1.45 |
| Profile 6 | | | | | |
| 0-18 | 214 | 94 | 25 | 670 | 3.14 |
| 18-55 | 233 | 2 | 12 | 493 | 2.12 |
| 55-78 | 304 | 2 | 13 | 306 | 1.01 |
| 78-103 | 377 | 2 | 11 | 323 | 0.86 |
| 103-130 | 377 | 1 | 8 | 360 | 0.96 |
| 130-158 | 359 | 2 | 7 | 353 | 0.99 |
| 158-183 | 460 | 1 | 6 | 626 | 1.36 |
| 183-211 | 482 | 1 | 5 | 683 | 1.42 |
| 211-236 | 445 | 1 | 5 | 615 | 1.38 |
| 236-260 | 438 | 1 | 5 | 610 | 1.39 |
| 260-285 | 418 | 1 | 6 | 575 | 1.38 |
| 285-310 | 410 | 1 | 5 | 610 | 1.49 |
| 310-346 | 475 | 1 | 5 | 785 | 1.65 |
| 346-371 | 448 | 1 | 5 | 665 | 1.49 |
| 371-383 | 463 | 1 | 6 | 705 | 1.52 |
| 383-400 | 445 | 1 | 6 | 650 | 1.46 |
| 400-430 | 385 | 1 | 6 | 525 | 1.36 |

Table 5. (continued)

| Depth | Mg | P | K | Ca | Ca:Mg |
|---|---|---|---|---|---|
| | ppm | | | | |
| Profile 7 | | | | | |
| 0-3 | 83 | 3 | 39 | 15 | 0.18 |
| 3-27 | 295 | 1 | 12 | 15 | 0.05 |
| 27-43 | 390 | 1 | 12 | 15 | 0.04 |
| 43-70 | 435 | 1 | 14 | 15 | 0.03 |
| 70-92 | 440 | 1 | 16 | 15 | 0.03 |
| 92-100 | 473 | 1 | 14 | 25 | 0.05 |
| 100-104 | 445 | 1 | 12 | 30 | 0.07 |

Examination of the data in Table 5 reveals the trends of increasing Mg and Ca with depth in those soils whose parent rock was high in those elements. That is, profiles 2, 5, and 6 demonstrate a general increase in extractable Ca with depth while all seven profiles show an increase in extractable Mg with depth. In a discussion of nutrient loss during pedogenesis, Simonson (1970) presents data which show similar trends. While much of the nutrient loss during soil formation occurs at the weathering front, weathering and nutrient removal continue to occur during and after horizon differentiation.

The levels of P are generally low in all of the profiles and can be related to the low P content of most rocks. The very high P level in the surface horizons of profile 6 is most likely due to fertilizer additions in the production of turfgrass.

Extractable K levels are fairly low in all seven profiles. Similar to Ca in the serpentine soils, all profiles show higher levels of extractable K in the surface horizon than in lower horizons. The possible explanations for this would be similar to those previously offered for higher Ca levels in surface horizons of serpentine soils.

## Soil Reaction and Base Saturation

Soil pH values for the seven profiles studied are presented in Table 6. Data for the remaining samples collected are located in Appendix B. While Wright and Foss (1972)

Table 6. Selected chemical data for the seven profiles studied.

| Depth cm | $Ca^{++}$ | $Mg^{++}$ | $K^{+}$ | $Ni^{++}$ | $H^{+}$ | $Ni^{++}$ ppm | CEC Summation | CEC $NH_4OAC$ | CEC of clay | % Base Saturation | pH | % Organic Carbon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | meq/100g | | | | | | meq/100g | | | | | |
| **Profile 1** | | | | | | | | | | | | |
| 0-6 | 4.2 | 5.4 | 0.2 | 0 | 8.8 | 1 | 18.6 | 11.6 | 117 | 52.7 | 5.6 | 2.98 |
| 6-21 | 2.3 | 3.3 | 0.1 | 0 | 7.3 | 1 | 13.0 | 9.7 | 81 | 43.8 | 5.4 | 1.04 |
| 21-26 | 1.0 | 4.5 | 0.1 | 0 | 6.4 | 1 | 12.0 | 8.7 | 82 | 46.7 | 5.6 | 0.50 |
| 26-32 | 1.4 | 13.3 | 0.1 | 0 | 6.5 | 1 | 21.3 | 11.8 | 86 | 69.5 | 5.9 | nd |
| 32-38 | 1.6 | 21.9 | 0.2 | tr | 7.1 | 2 | 30.8 | 15.8 | 97 | 76.9 | 6.1 | 0.38 |
| 38-60(si) | 0.7 | 16.6 | 0.2 | tr | 4.0 | 2 | 21.5 | 11.5 | 121 | 81.4 | 6.8 | nd |
| 38-60(c) | 1.1 | 34.7 | 0.3 | tr | 6.5 | 3 | 42.6 | 22.8 | 117 | 84.7 | 6.6 | nd |
| 38-60(g) | 0.8 | 17.4 | 0.1 | tr | 5.2 | 3 | 23.5 | 14.9 | 149 | 77.9 | 6.6 | nd |
| **Profile 2** | | | | | | | | | | | | |
| 0-11 | 4.3 | 4.1 | 0.1 | tr | 8.7 | 2 | 17.2 | 11.4 | 97 | 49.4 | 5.2 | 1.71 |
| 11-13 | 5.0 | 6.8 | 0.1 | tr | 6.3 | 2 | 18.2 | 10.6 | 87 | 65.4 | 5.6 | 0.69 |
| 13-29 | 10.0 | 14.5 | 0.2 | tr | 7.8 | 2 | 32.5 | 18.0 | 109 | 76.0 | 5.8 | nd |
| 29-45 | 14.9 | 22.4 | 0.3 | tr | 9.2 | 2 | 46.8 | 28.1 | 113 | 80.3 | 6.0 | nd |
| 45-54 | 15.6 | 22.4 | 0.3 | 0 | 7.6 | 1 | 45.9 | 28.4 | 150 | 83.4 | 6.4 | nd |
| 54-75 | 16.0 | 20.5 | 0.3 | 0 | 5.6 | 1 | 42.4 | 25.5 | 199 | 86.8 | 6.8 | 0.18 |
| 75-92 | 6.4 | 7.0 | 0.1 | 0 | 2.1 | 0 | 15.6 | 9.4 | 246 | 86.5 | 7.2 | nd |
| 92-110 | 6.4 | 4.5 | 0.1 | 0 | 1.8 | 0 | 12.8 | 8.8 | 650 | 85.9 | 7.2 | nd |
| 110-138 | 17.0 | 17.6 | 0.2 | 0 | 5.1 | 1 | 39.9 | 27.1 | 202 | 87.2 | 6.9 | nd |
| 138-154 | 13.7 | 15.0 | 0.2 | 0 | 4.1 | 1 | 33.0 | 22.6 | 270 | 87.6 | 6.8 | nd |
| **Profile 3** | | | | | | | | | | | | |
| 0-4 | 9.3 | 5.6 | 0.3 | tr | 12.2 | 12 | 27.4 | 17.7 | 208 | 55.5 | 5.4 | 4.26 |
| 4-16 | 1.2 | 5.6 | 0.1 | tr | 6.6 | 8 | 13.5 | 11.4 | 91 | 51.1 | 5.6 | 0.84 |
| 16-28 | 0.5 | 13.6 | 0.1 | tr | 6.6 | 10 | 20.8 | 11.9 | 107 | 68.3 | 5.9 | nd |
| 28-40 | 0.6 | 25.0 | 0.3 | tr | 7.7 | 12 | 33.6 | 22.1 | 102 | 77.1 | 6.1 | nd |

nd = not determined

Table 6 (continued)

| Depth cm | $Ca^{++}$ | $Mg^{++}$ | $K^{+}$ | $Ni^{++}$ | $H^{+}$ | $Ni^{++}$ ppm | CEC Summation | CEC $NH_4OAC$ | CEC of clay | % Base Saturation | pH | % Organic Carbon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | meq/100g | | | | | | meq/100g | | | | | |
| Profile 3 (continued) | | | | | | | | | | | | |
| 40-53 | 0.7 | 25.3 | 0.3 | 0.1 | 7.2 | 17 | 33.6 | 20.8 | 113 | 78.6 | 6.4 | nd |
| 53-75 | 0.8 | 23.9 | 0.2 | 0.1 | 7.1 | 23 | 32.1 | 21.6 | 103 | 77.9 | 6.5 | 0.25 |
| 75-91 | 1.0 | 23.6 | 0.3 | 0.1 | 7.6 | 34 | 32.6 | 24.7 | 122 | 76.7 | 6.6 | nd |
| 91-107 | 1.3 | 30.7 | 0.3 | 0.1 | 8.3 | 38 | 40.7 | 25.4 | 167 | 79.6 | 6.6 | nd |
| 107-123 | 1.0 | 28.8 | 0.2 | 0.2 | 8.1 | 44 | 38.3 | 23.4 | 178 | 78.9 | 6.6 | nd |
| 123-139 | 0.8 | 17.6 | 0.1 | 0.1 | 5.0 | 24 | 23.6 | 14.8 | 169 | 78.8 | 6.6 | nd |
| 139-155 | 0.6 | 13.0 | 0.1 | 0.1 | 3.9 | 25 | 17.7 | 10.0 | 139 | 78.0 | 6.8 | nd |
| 155-170 | 0.7 | 15.0 | 0.1 | 0.1 | 3.9 | 19 | 19.8 | 13.3 | 135 | 80.3 | 6.6 | nd |
| Profile 4 | | | | | | | | | | | | |
| 0-2 | 6.0 | 7.7 | 0.4 | tr | 31.3 | 2 | 45.4 | 34.8 | 196 | 31.1 | 4.4 | 13.51 |
| 2-8 | 0.6 | 4.3 | 0.1 | tr | 11.4 | 7 | 16.4 | 10.4 | 82 | 30.5 | 5.0 | 1.80 |
| 2-18 | 0.6 | 7.5 | 0.1 | tr | 8.3 | 11 | 16.5 | 9.8 | 82 | 49.7 | 5.6 | 1.38 |
| 18-26 | 0.4 | 10.0 | 0.1 | tr | 5.9 | 6 | 16.4 | 9.2 | 114 | 64.0 | 6.3 | nd |
| 26-43 | 0.2 | 12.7 | 0.1 | tr | 5.1 | 5 | 18.1 | 10.7 | 89 | 71.8 | 6.6 | 0.52 |
| 41-43 | 0.3 | 13.1 | 0.1 | tr | 3.8 | 6 | 17.3 | 9.6 | 86 | 78.0 | 6.8 | nd |
| Profile 5 | | | | | | | | | | | | |
| 0-6 | 0.4 | 0.5 | 0.2 | 0 | 13.2 | 0 | 14.3 | 8.5 | 100 | 7.7 | 4.4 | 2.67 |
| 6-16 | 0.2 | 0.3 | 0.1 | 0 | 8.8 | 0 | 9.4 | 6.5 | 69 | 6.4 | 4.5 | 0.78 |
| 16-32 | 0.2 | 1.1 | 0.1 | 0 | 10.0 | 0 | 11.4 | 7.8 | 54 | 12.3 | 4.7 | nd |
| 32-55 | 0.4 | 4.3 | 0.1 | 0 | 13.0 | 0 | 17.8 | 12.6 | 65 | 27.0 | 4.8 | nd |
| 55-75 | 1.6 | 5.6 | 0.1 | 0 | 10.0 | 0 | 17.3 | 11.9 | 63 | 42.2 | 5.0 | 0.11 |
| 75-95 | 3.3 | 7.3 | 0.1 | 0 | 7.7 | 1 | 18.4 | 10.1 | 82 | 58.2 | 5.3 | nd |
| 95-110 | 6.8 | 10.0 | 0.1 | 0 | 4.2 | 1 | 21.1 | 14.5 | 104 | 80.1 | 5.8 | 0.04 |
| 110-130 | 6.4 | 8.5 | 0.1 | 0 | 3.4 | 1 | 18.4 | 12.5 | 166 | 81.5 | 6.2 | 0.06 |
| 130-155 | 11.4 | 11.9 | 0.1 | 0 | 3.9 | 1 | 27.3 | 17.6 | 338 | 85.7 | 6.4 | nd |
| 155-175 | 6.8 | 6.6 | 0.1 | 0 | 2.2 | 0 | 15.7 | 8.7 | 536 | 86.0 | 6.6 | 0.05 |
| 175-205 | 7.8 | 4.0 | 0.2 | 0 | 2.6 | 0 | 14.6 | 10.9 | 438 | 82.2 | 6.4 | nd |

nd = not determined

Table 6 (continued)

| Depth cm | $Ca^{++}$ | $Mg^{++}$ | $K^{+}$ | $Ni^{++}$ | $H^{+}$ | $Ni^{++}$ ppm | CEC Summation | CEC $NH_4OAC$ | CEC of clay | % Base Saturation | pH | % Organic Carbon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | meq/100g | | | | | | meq/100g | | | | | |
| Profile 6 | | | | | | | | | | | | |
| 0-18 | 8.3 | 1.2 | 0.2 | 0 | 5.7 | 0 | 15.4 | 8.2 | 88 | 63.0 | 6.4 | 0.99 |
| 18-55 | 8.0 | 2.3 | 0.1 | 0 | 15.0 | 0 | 25.4 | 21.4 | 53 | 40.9 | 4.7 | 0.28 |
| 55-78 | 5.9 | 7.8 | 0.1 | 0 | 18.7 | 1 | 32.5 | 29.9 | 58 | 42.5 | 4.5 | nd |
| 78-103 | 9.4 | 16.0 | 0.1 | tr | 23.1 | 2 | 48.6 | 42.0 | 99 | 52.5 | 4.6 | nd |
| 103-130 | 10.8 | 17.2 | 0.1 | tr | 16.6 | 3 | 44.7 | 36.7 | 160 | 62.9 | 4.7 | 0.04 |
| 130-158 | 8.9 | 14.1 | 0.1 | tr | 10.7 | 4 | 33.8 | 26.8 | 113 | 68.3 | 4.8 | nd |
| 158-183 | 22.0 | 36.4 | 0.1 | tr | 14.8 | 12 | 73.3 | 53.8 | 286 | 79.8 | 4.7 | nd |
| 183-211 | 23.0 | 32.6 | tr | tr | 10.4 | 12 | 66.0 | 50.3 | 503 | 84.2 | 4.9 | nd |
| 211-236 | 22.6 | 30.7 | tr | tr | 8.8 | 11 | 62.1 | 44.2 | 536 | 85.8 | 5.2 | nd |
| 236-260 | 21.4 | 33.3 | tr | tr | 9.0 | 10 | 63.7 | 48.4 | 809 | 85.9 | 5.2 | nd |
| 260-285 | 14.4 | 19.8 | tr | tr | 4.7 | 6 | 38.9 | 28.7 | 387 | 87.9 | 5.4 | nd |
| 285-310 | 14.6 | 19.3 | tr | tr | 4.8 | 6 | 38.7 | 29.0 | 456 | 87.6 | 5.4 | nd |
| 310-346 | 20.2 | 23.2 | tr | tr | 5.8 | 7 | 49.2 | 34.0 | 1,149 | 88.2 | 5.5 | nd |
| 346-371 | 22.2 | 25.4 | tr | tr | 5.6 | 7 | 53.2 | 35.8 | 795 | 89.5 | 5.4 | nd |
| 371-383 | 27.2 | 31.8 | 0.1 | tr | 7.8 | 8 | 66.9 | 49.0 | 1,029 | 88.3 | 5.5 | nd |
| 383-400 | 25.4 | 30.9 | tr | tr | 7.8 | 7 | 64.1 | 46.8 | 1,161 | 87.8 | 5.7 | nd |
| 400-430 | 15.0 | 21.3 | tr | tr | 5.6 | 5 | 41.9 | 34.0 | 1,225 | 86.6 | 5.8 | nd |
| Profile 7 | | | | | | | | | | | | |
| 0-3 | 0.2 | 0.9 | 0.2 | tr | 17.9 | 5 | 19.2 | 11.6 | 107 | 6.8 | 4.4 | 4.46 |
| 3-27 | 0.2 | 3.4 | 0.1 | 0.1 | 6.9 | 40 | 10.7 | 7.1 | 60 | 35.5 | 5.4 | 0.59 |
| 27-43 | 0.2 | 10.5 | 0.1 | 0.1 | 6.4 | 19 | 17.3 | 10.5 | 79 | 63.0 | 6.4 | nd |
| 43-70 | 0.2 | 8.4 | 0.2 | 0.1 | 5.4 | 15 | 14.3 | 10.3 | 63 | 62.2 | 6.6 | nd |
| 70-92 | 0.2 | 11.4 | 0.1 | 0.1 | 5.7 | 17 | 17.5 | 10.0 | 81 | 67.4 | 6.6 | 0.28 |
| 92-100 | 0.2 | 24.4 | 0.1 | 0.1 | 6.4 | 37 | 31.2 | 21.7 | 120 | 79.5 | 6.6 | nd |
| 100-104 | 0.3 | 28.7 | 0.1 | 0.2 | 5.8 | 48 | 35.1 | 24.5 | 151 | 83.5 | 6.8 | nd |

nd = not determined

recognized the great variability of soil pH in the Maryland Piedmont, they reported that most of these soils exhibit a pH minimum in the C horizon. In contrast then to many Piedmont soils, these seven profiles which have formed from mafic and ultramafic parent materials, have pH values which increase with depth.

The surface horizons of the four serpentine soils show pH values between 4.4 and 5.6. These values steadily increase with depth to between 6.6 and 6.8 in the lowest horizons. The base saturation data for these soils, which are found in Table 6, exhibit a similar trend of increasing values with depth. Figure 7 shows the relationship between pH and base saturation for samples from the serpentinite-derived soils. The high correlation coefficient indicates a close relationship between these two parameters. This is congruent with the report of Wright and Foss (1972).

Similar trends were present in two of the profiles formed from non-serpentine parent materials. Profile 6, however, was anomalous in that while the base saturation increased with depth to nearly 90 percent, the pH values still remained strongly acid. Work by Mehlich (1941; 1942) has shown that at a given percent base saturation, soils higher in 2:1 minerals will demonstrate a lower pH than soils higher in 1:1 minerals. X-ray diffraction data show that the less than 5 μm fractions of this soil are high in 2:1 minerals. Previously described PVC data have further suggested the presence of

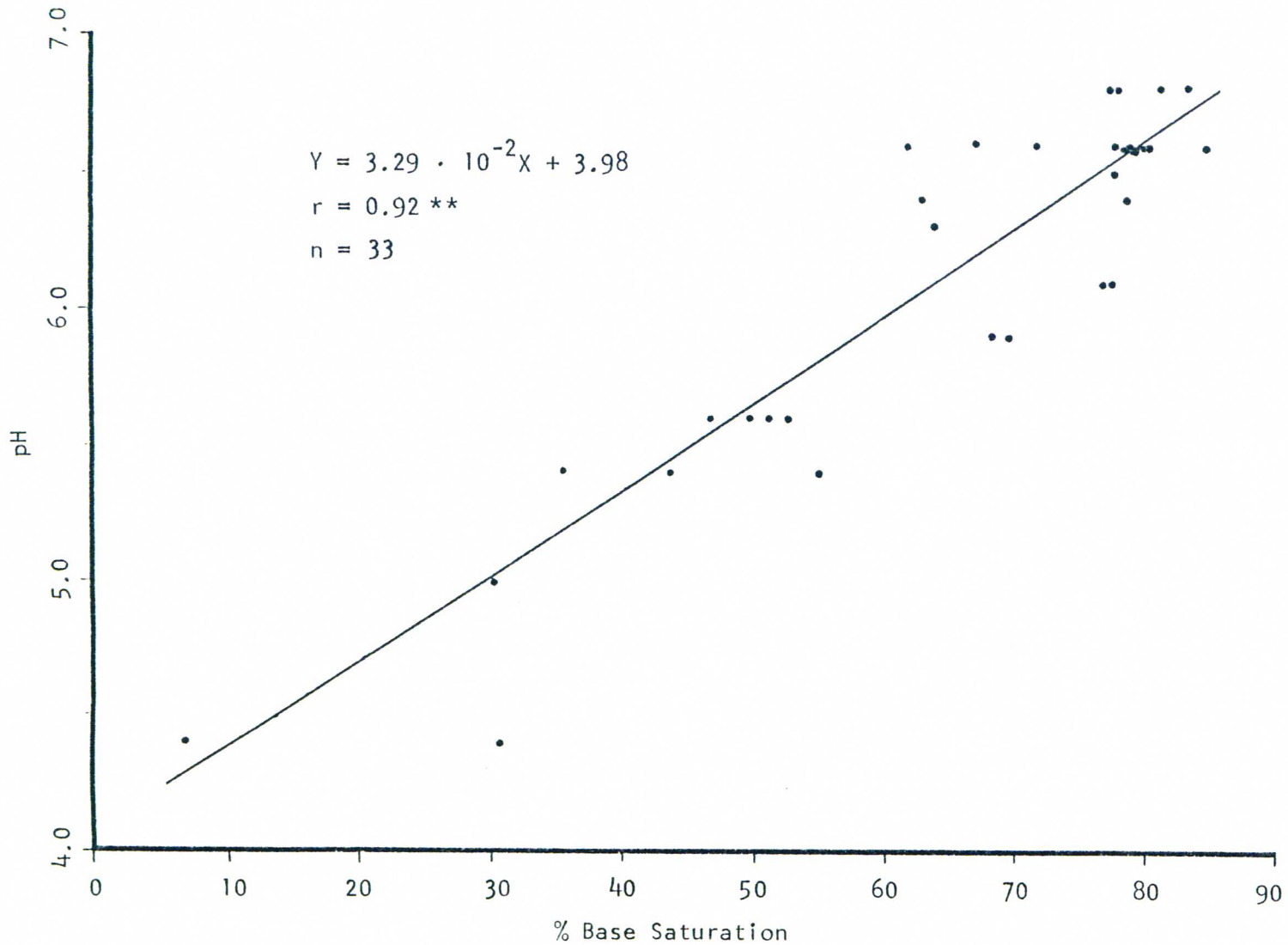



Figure 7. Percentage base saturation vs. pH for all horizons from four profiles formed from serpentinite

**Significant at 1% level.

expansible 2:1 minerals in the coarser soil fractions. This would explain the low pH values in the presence of a high percent base saturation.

Exchangeable Cations

It can be seen from Table 6 that $Ca^{++}$ and $Mg^{++}$ are the two most prominent bases on the exchange complex of the soils studied. Considering the mafic nature of the parent materials, this is not unexpected. In those soils derived from serpentinite, $Mg^{++}$ strongly dominates the exchange complex and reaches a maximum level in the B horizon. This maximum in the B horizon is probably the result of a combination of downward leaching by acid waters and the greater capacity for cation retention in the B horizon due to the greater amounts of clay (Frohlinger & Kane, 1975; Schnitzer & Desjardins, 1969). Exchangeable calcium is present at very low levels, and similar to extractable Ca, is commonly present at maximum levels in the surface horizon.

In the non-serpentine soils, however, $Ca^{++}$ and $Mg^{++}$ occur on the exchange complex at levels which are roughly comparable. In profile 2, the maximum levels of exchangeable $Ca^{++}$ and $Mg^{++}$ occur in the B horizon while in profile 5, the maximum occurs beneath the lithologic discontinuity in the IIB3 and IIC1 horizons developed from metagabbro residuum. The maximum levels in profile 6 are in the C horizons; this is probably due to the very high exchange capacity.

The levels of exchangeable $K^+$ in all seven of these soils are generally low, ranging from trace amounts to 0.3 meq/100 grams. A few of the surface samples had greater amounts present. These levels are not, however, unusually low but rather represent values common for many soils in Maryland (Foss et al., 1969; 1971).

All soils except profile 5 contained at least trace amounts of exchangeable $Ni^{++}$ in some portion of the profile. Of the serpentinite-derived soils, profile 1 showed a maximum of 3 ppm exchangeable $Ni^{++}$, while profiles 3, 4, and 7 showed considerably higher levels of up to 48 ppm. Profile 6, which developed from amphibolite, had exchangeable $Ni^{++}$ values as high as profile 4 and higher than profile 1, both of which formed from serpentinite. This suggests that $Ni^{++}$ was present in the amphibole structure of the parent material. This also demonstrates that very high levels of Ni are not present in all serpentine soils (Soane & Saunder, 1959; Walker, 1954).

## Cation Exchange Capacity

Values for cation exchange capacity (CEC) are presented in Table 6. In six of the seven profiles studied, the CEC of the surface horizon is greater than the horizon underlying it. This is due to the large contribution made by organic matter which is present in these surface samples. The only exception is profile 6 wherein the horizon underlying the Ap has a very high clay content which has more than compensated for the reduction in organic matter.

Nearly all of the samples have exchange capacities which are greater than 12.5 meq/100 g, which is the mean value for CEC by summation for Maryland Piedmont B horizons reported by Wright and Foss (1972). X-ray diffraction data show that vermiculite and/or montmorillonite are present in these soils which would account for the higher values.

Table 6 also shows data for CEC calculated on the basis of 100 grams of clay. Approximate values for the CEC of pure vermiculite and montmorillonite clay are 160 meq/100 g and 110 meq/100 g respectively (Borchardt, 1977; Douglas, 1977). Many of the calculated values are greater than those values and in some cases are much greater. One extreme case is the C6 horizon of profile 6, which when calculated has a CEC/100 g clay of over 1100 meq. X-ray diffraction data show that some minerals with lower CEC values are present in the clay fractions. These data, in conjunction with PVC measurements, show that some expansible 2:1 clay minerals are present in coarser particle size fractions. It appears then, that in these soils formed from mafic and ultramafic parent materials, the mineralogy is as important, or perhaps more important, than the percent clay in determining the CEC.

The CEC of the soils studied was determined both by the $NH_4OAC$ replacement method and by summation of cations. The CEC values by these two methods were highly correlated (r = 0.98**) and in all cases the values determined by the $NH_4OAC$ method were lower, representing between 51 and 92 percent of the CEC

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**Significant at 1% level.

by summation. Wright (1969) has described the effects of pH-induced CEC, the inability of $NH_4OAC$ to completely replace $H^+$ and $Al^{+++}$ on the exchange sites of organic materials and 1:1 clays, and the fixation of $NH_4^+$ by some expansible 2:1 minerals as possible explanations of the discrepancies between these two methods of analysis. The occurrence of vermiculite in these soils as well as the presence of some 1:1 clay minerals and organic matter suggests that all three of the above factors may have contributed to the differences in results by the two methods.

Total Ni and Cr

Data for total nickel and chromium for the profiles studied are presented in Table 7. Profiles 2 and 5, which have formed from non-serpentine parent materials, showed very low levels of total Ni throughout the profile. Levels at or near zero were found in the silt mantle of profile 5. Profile 6, which was also derived from non-serpentine rock, had levels of total Ni at or near zero in the upper meter of soil, but increasing to between 100 and 200 ppm deeper in the profile. These values are slightly higher than the values reported by Shewry and Peterson (1976) for concentrated $HNO_3$ soluble Ni of two non-serpentine soils in England, and are lower than those found in all of the serpentinite-derived soils in this study.

Of the four serpentine soils, profile 1 had the lowest levels of both total Ni and total Cr. This was followed by

Table 7. Elemental analyses of soils

| | Depth cm | Total Ni | Total Cr | Total $Fe_2O_3$ | Free $Fe_2O_3$ | Structural $Fe_2O_3$ | Structural $Fe_2O_3$: Total $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|
| | | ppm | | | % | | |
| Profile 1 | | | | | | | |
| 6202 | 0-6 | 180 | 800 | 7.25 | 3.17 | 4.08 | 56.3 |
| 03 | 6-21 | 180 | 650 | 8.77 | 3.75 | 5.02 | 57.3 |
| 04 | 21-26 | 200 | 600 | 8.47 | 3.85 | 4.62 | 54.5 |
| 05 | 26-32 | 220 | 400 | 7.54 | 4.15 | 3.39 | 45.0 |
| 06 | 32-38 | 280 | 400 | 7.81 | 4.66 | 3.15 | 40.3 |
| 07 | 38-60(Si) | 390 | 550 | 7.88 | 3.66 | 4.22 | 53.6 |
| 08 | 38-60(c) | nd | nd | nd | 4.28 | nd | nd |
| 09 | 38-60(g) | nd | nd | nd | 6.38 | nd | nd |
| Profile 2 | | | | | | | |
| 6210 | 0-11 | 60 | nd | 6.38 | 2.67 | 3.71 | 54.3 |
| 11 | 11-13 | 50 | nd | 7.31 | 2.76 | 4.55 | 62.2 |
| 12 | 13-29 | 60 | nd | 8.58 | 3.59 | 4.99 | 58.2 |
| 13 | 29-45 | 80 | nd | 10.74 | 3.16 | 7.58 | 70.6 |
| 14 | 45-54 | 90 | nd | 10.65 | 1.90 | 8.75 | 82.2 |
| 15 | 54-75 | 70 | nd | 9.67 | 1.46 | 8.21 | 84.9 |
| 16 | 75-92 | 60 | nd | 7.75 | 0.61 | 6.94 | 89.5 |
| 17 | 92-110 | 70 | nd | 8.11 | 0.29 | 7.82 | 96.4 |
| 18 | 110-138 | 70 | nd | 9.38 | 0.77 | 8.61 | 91.8 |
| 19 | 138-154 | 60 | nd | 9.15 | 0.61 | 8.54 | 93.3 |
| Profile 3 | | | | | | | |
| 6220 | 0-4 | 730 | 1,550 | 5.31 | 2.75 | 2.56 | 48.2 |
| 21 | 4-16 | 670 | 2,650 | 6.45 | 3.80 | 2.65 | 41.1 |
| 22 | 16-28 | 970 | 2,150 | 8.79 | 4.25 | 4.54 | 51.6 |
| 23 | 28-40 | 1,800 | 1,900 | 10.88 | 5.45 | 5.43 | 49.9 |

nd = not determined

Table 7 (continued)

| | Depth cm | Total Ni | Total Cr | Total $Fe_2O_3$ | Free $Fe_2O_3$ | Structural $Fe_2O_3$ | Structural $Fe_2O_3$ Total $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|
| | | ppm | | % | | | |
| Profile 3 (continued) | | | | | | | |
| 6224 | 40-53 | 2,950 | 4,000 | 14.66 | 6.59 | 8.07 | 55.0 |
| 25 | 53-75 | 6,160 | 5,850 | 21.42 | 7.39 | 14.03 | 65.5 |
| 26 | 75-91 | 9,660 | 1,600 | 20.25 | 10.22 | 10.03 | 49.5 |
| 27 | 91-107 | 8,200 | 3,250 | 22.87 | 10.25 | 12.62 | 55.2 |
| 28 | 107-123 | 18,900 | 1,650 | 22.91 | 8.49 | 14.42 | 62.9 |
| 29 | 123-139 | 5,900 | 1,450 | 15.92 | 6.48 | 9.44 | 59.3 |
| 30 | 139-155 | 5,740 | 800 | 17.56 | 7.05 | 10.51 | 59.9 |
| 31 | 155-170 | 5,400 | 850 | 15.94 | 6.91 | 9.03 | 56.6 |
| Profile 4 | | | | | | | |
| 6232 | 0-2 | 390 | 850 | 4.35 | 2.47 | 1.88 | 43.2 |
| 33 | 2-8 | 530 | 950 | 5.55 | 3.06 | 2.49 | 44.9 |
| 34 | 2-18 | 690 | 1,300 | 6.66 | 3.53 | 3.13 | 47.0 |
| 35 | 18-26 | 1,050 | 1,400 | 9.84 | 4.16 | 5.68 | 57.7 |
| 36 | 26-43 | 1,080 | 900 | 8.49 | 3.69 | 4.80 | 56.5 |
| 37 | 41-43 | 1,440 | 1,050 | 8.72 | 3.47 | 5.25 | 60.2 |
| Profile 5 | | | | | | | |
| 6238 | 0-6 | 20 | nd | 2.52 | 1.66 | 0.86 | 34.1 |
| 39 | 6-16 | 10 | nd | 4.25 | 2.50 | 1.75 | 41.2 |
| 40 | 16-32 | 10 | nd | 4.22 | 2.62 | 1.60 | 37.9 |
| 41 | 32-55 | 0 | nd | 5.83 | 3.09 | 2.74 | 47.0 |
| 42 | 55-75 | 0 | nd | 4.98 | 2.52 | 2.46 | 49.4 |
| 43 | 75-95 | 0 | nd | 5.41 | 2.62 | 2.79 | 51.6 |
| 44 | 95-110 | 30 | nd | 6.84 | 1.00 | 5.84 | 85.4 |
| 45 | 110-130 | 40 | nd | 6.18 | 0.72 | 5.46 | 88.3 |

nd = not determined

Table 7 (continued)

| | Depth cm | Total Ni | Total Cr | Total $Fe_2O_3$ | Free $Fe_2O_3$ | Structural $Fe_2O_3$ | Structural $Fe_2O_3$ Total $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|
| | | ppm | | % | | | |
| Profile 5 (continued) | | | | | | | |
| 6246 | 130-155 | 50 | nd | 7.08 | 0.83 | 6.25 | 88.3 |
| 47 | 155-175 | 30 | nd | 4.42 | 0.26 | 4.16 | 94.1 |
| 48 | 175-205 | 30 | nd | 5.72 | 0.83 | 4.89 | 85.5 |
| Profile 6 | | | | | | | |
| 6249 | 0-18 | 20 | nd | 3.27 | 2.40 | .87 | 26.6 |
| 50 | 18-55 | 0 | nd | 11.48 | 6.68 | 4.80 | 41.8 |
| 51 | 55-78 | 0 | nd | 14.54 | 7.71 | 6.83 | 47.0 |
| 52 | 78-103 | 20 | nd | 15.04 | 7.31 | 7.73 | 51.4 |
| 53 | 103-130 | 170 | nd | 10.20 | 3.07 | 7.13 | 69.9 |
| 54 | 130-158 | 90 | nd | 5.98 | 2.37 | 3.61 | 60.4 |
| 55 | 158-183 | 180 | nd | 10.97 | 1.54 | 9.43 | 86.0 |
| 56 | 183-211 | 160 | nd | 8.94 | .84 | 8.10 | 90.6 |
| 57 | 211-236 | 190 | nd | 7.95 | .74 | 7.21 | 90.7 |
| 58 | 236-260 | 150 | nd | 8.69 | .79 | 7.90 | 90.9 |
| 59 | 260-285 | 120 | nd | 2.22 | .37 | 1.85 | 83.3 |
| 60 | 285-310 | 120 | nd | 2.95 | .46 | 2.49 | 84.4 |
| 61 | 310-346 | 120 | nd | 4.56 | .43 | 4.13 | 90.6 |
| 62 | 346-371 | 160 | nd | 4.78 | .72 | 4.06 | 84.9 |
| 63 | 371-383 | 140 | nd | 10.54 | 1.57 | 8.97 | 85.1 |
| 64 | 383-400 | 120 | nd | 10.64 | .89 | 9.75 | 91.6 |
| 65 | 400-430 | 100 | nd | 10.12 | .63 | 9.49 | 93.8 |

nd = not determined

Table 7 (continued)

| | Depth cm | Total Ni | Total Cr | Total $Fe_2O_3$ | Free $Fe_2O_3$ | Structural $Fe_2O_3$ | Structural $Fe_2O_3$ Total $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|
| | | ppm | | | % | | |
| Profile 7 | | | | | | | |
| 6266 | 0-3 | 700 | 1,950 | 5.61 | 3.42 | 2.19 | 39.0 |
| 67 | 3-27 | 1,100 | 2,550 | 8.29 | 5.01 | 3.28 | 39.6 |
| 68 | 27-43 | 1,840 | 1,550 | 10.81 | 6.12 | 4.69 | 43.4 |
| 69 | 43-70 | 1,640 | 1,450 | 9.14 | 5.26 | 3.88 | 42.5 |
| 70 | 70-92 | 1,370 | 1,400 | 8.07 | 4.63 | 3.44 | 42.6 |
| 71 | 92-100 | 3,250 | 1,300 | 10.64 | 4.80 | 5.84 | 54.9 |
| 72 | 100-104 | 3,430 | 650 | 10.21 | 4.12 | 6.09 | 59.6 |

profiles 4, 7, and 3 in order of increasing mean levels of both total Ni and Cr. It is not surprising that profile 3 is highest in total Cr since the soil is located on the Soldiers Delight serpentinite body, parts of which were once mined for chromite. Although the mean values for each of the four serpentine soils show a high correlation between total Ni and total Cr ($r = 0.96^{**}$), there appears to be no significant overall correlation between total Ni and Cr for individual samples ($r = 0.25^{\S}$).

The values for total Ni show an increase with depth in the four serpentine profiles. This is probably due to the greater intensity and duration of weathering and consequent release and removal of Ni in horizons nearer to the soil surface (Simonson, 1970). In some cases, however, the addition of windblown material to the soil surface may have had the net effect of decreasing Ni levels by dilution. No similar trends are apparent for levels of total Cr.

Total and Structural Iron

Data for total $Fe_2O_3$, free $Fe_2O_3$, and structural $Fe_2O_3$ are presented in Table 7. Structural $Fe_2O_3$ was calculated as the difference between total and dithionite extractable $Fe_2O_3$. Values for total and free iron are generally high in the profiles studied. For the serpentinite-derived soils, this indicates substantial substitution of Fe for Mg in the minerals of the parent rock and the probable occurrence of Fe-rich accessory minerals. This is especially pronounced in

**Significant at 1% level. §Non-significant.

profile 3 where the structural iron content, as $Fe_2O_3$, is 14.4 percent in the C horizon.

In those soils with deeper profiles, the levels of structural $Fe_2O_3$ tend to increase with depth to a maximum between 50 and 100 cm. Below this depth, the iron content is more variable, but is generally high. The initial increase with depth is probably the result of longer and more intense weathering of iron-bearing minerals near the surface which have released $Fe_2O_3$ from the structures (Simonson, 1970). This is further reflected by the increase in percent structural $Fe_2O_3$ of the total $Fe_2O_3$ with depth. The greater variation in the lower portions of the profiles, such as in profile 6, may reflect variability in composition of the parent rock or differential weathering.

Free Iron Oxides

Data for clay content and free iron oxides are presented in Figure 8. In all cases, the percent $Fe_2O_3$ levels increase from the A to the B2 horizon. This probably results from the weathering and transport of Fe to the B horizon. Possible mechanisms for the translocation of Fe include solutions of reduced iron under acid conditions, movement by humus-protected soils, and the formation of and movement as metal-organic complexes (Stobbe & Wright, 1959).

The clay distribution and free iron oxide distribution are significantly correlated at the 1 percent level within

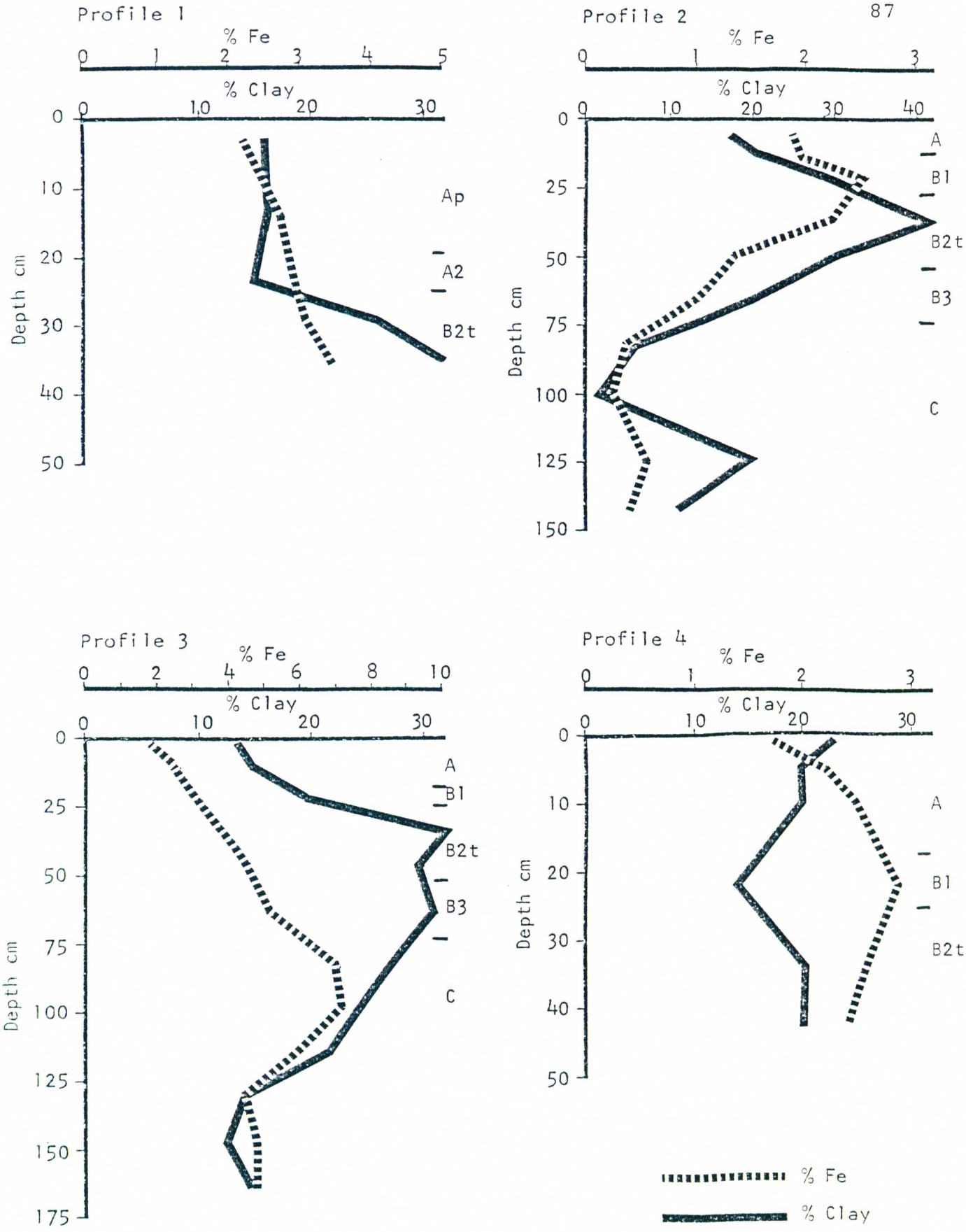



Figure 8. Distribution of percentage free Fe and percentage clay with depth in the seven study profiles.

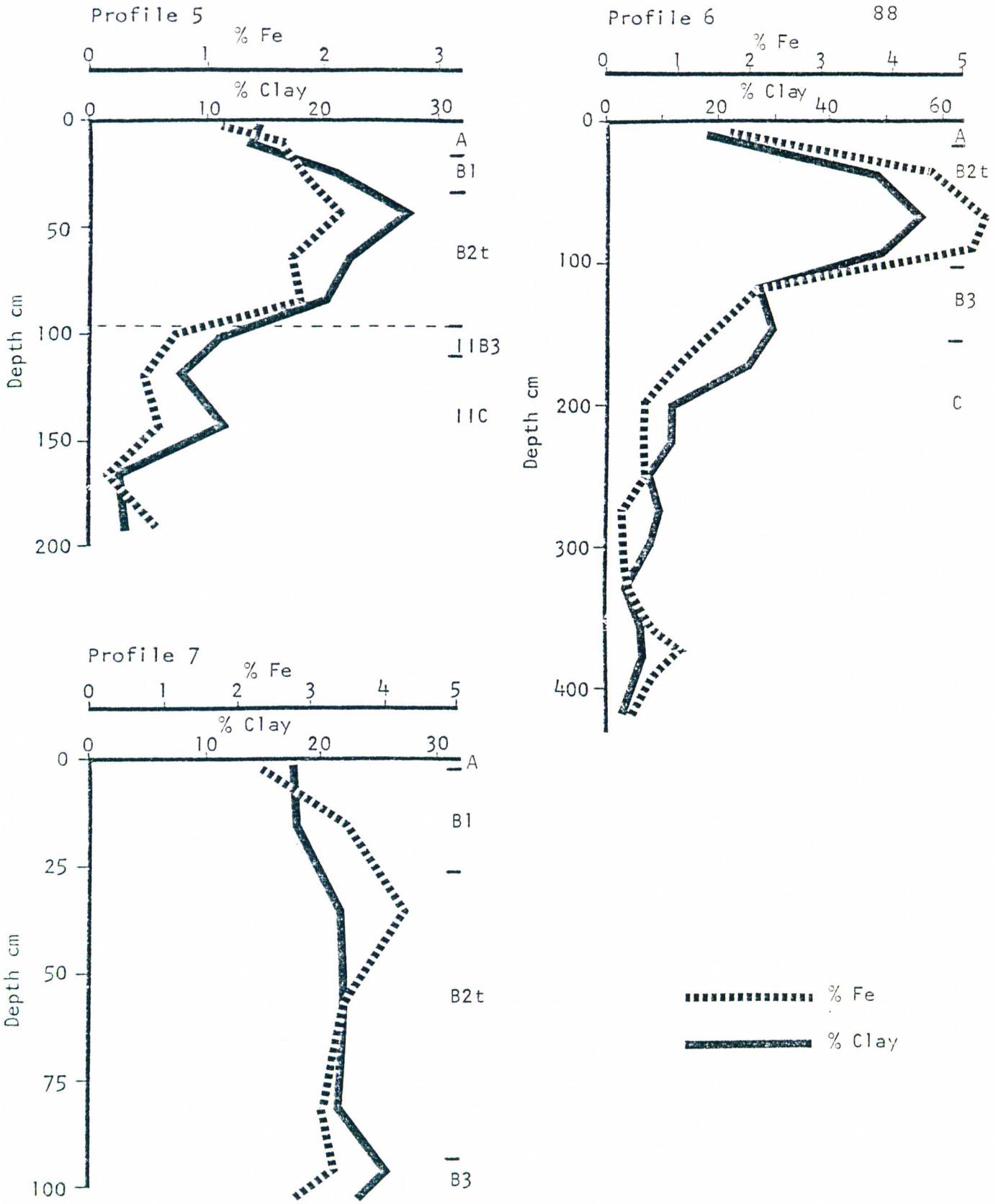



Figure 8. (continued)

profiles 2, 5, and 6 which have formed from non-serpentine mafic rocks (r values are 0.78, 0.92, and 0.96 respectively). Of the serpentine soils, only profile 1 shows a significant (5 percent level) positive relationship between percent clay and percent free iron (r = 0.88). Wright (1972) has reported similar findings for two Paleudults of the Maryland Coastal Plain. Data presented by Soileau and McCracken (1967) on North Carolina Coastal Plain soils also demonstrated this relationship. This suggests that the release and translocation of iron oxides parallels the formation and translocation of clay in these soils.

In profile 3, the $Fe_2O_3$ maximum occurs deeper in the profile than does the clay maximum. The somewhat poor drainage of this profile may have contributed to the greater mobility and translocation of Fe; however, profile 5, which also has impeded drainage, does not demonstrate the same characteristics. The very high levels of structural iron present in the same portion of the profile as the Fe oxide maximum (Table 7) suggests that perhaps the Fe content of the parent material was not uniform, and that weathering and release of Fe in situ is responsible for this Fe oxide maximum below the clay maximum.

## Elemental Analysis of Silts

Over the past two decades, the X-ray spectrographic analysis of silts for elemental determinations has been shown to be a useful tool in studying the genesis of soils (Alexander et al., 1962; Beavers, 1960; Fanning & Jackson, 1967; Foss et

al., 1978; Foss & Rust, 1968). Although most widely used in the study of loess-derived soils, this approach has also been used in the study of soils formed from alluvium, glacial till, and sedimentary rocks (Chapman & Horn, 1968; Foss & Rust, 1968; Smith and Buol, 1968). This technique is based on the assumption that all of the Zr and Ti occurs in resistant minerals such as zircon and rutile, and that Ca, K, and Fe occur primarily in minerals which are less resistant such as feldspars, amphiboles, and pyroxenes. Therefore, evaluation of the elemental distribution through the profiles should provide information on the degree of weathering and the homogeneity of parent materials.

The profile distributions of $ZrO_2$, $TiO_2$, CaO, $K_2O$, and $Fe_2O_3$ for the coarse and fine silts are presented in Figure 9. Profiles 1 and 4 are shallow soils and the elemental distribution in these profiles shows a low degree of weathering. The contents of $ZrO_2$ and $TiO_2$ are comparable for the two profiles and show a slight decrease with depth due to the concentration of resistant minerals containing Ti and Zr toward the surface. Values for $K_2O$ are also comparable for these two soils, but due to the occurrence of K in less resistant minerals, the values tend to increase slightly with depth. Although the CaO levels in profile 1 are two to three times higher than those in profile 4, both of these soils also show a slight increase in CaO levels in the coarse and fine silt fractions with depth. As a result of the low degree of weathering in

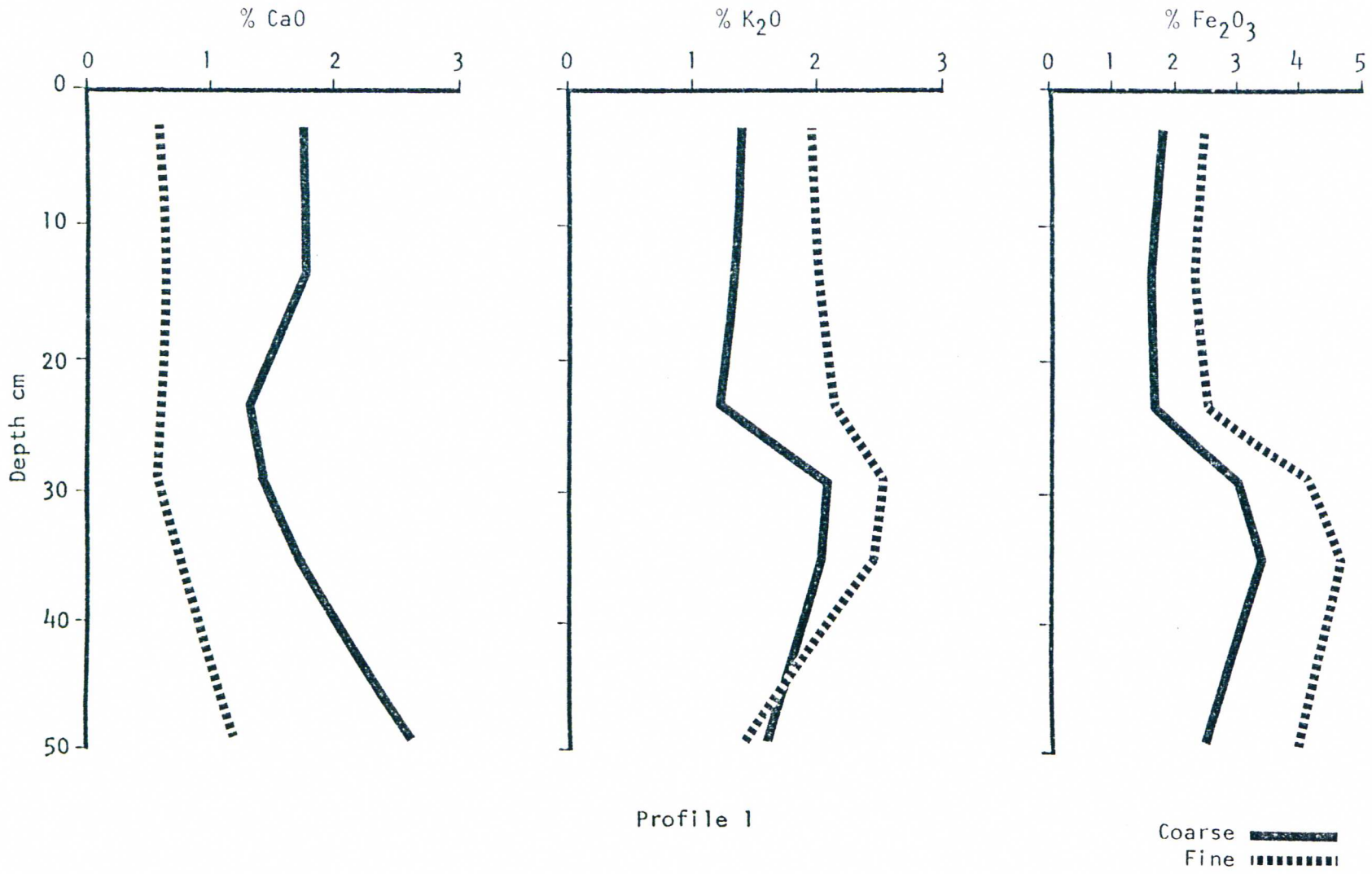



Figure 9. Distribution of CaO, $K_2O$, $Fe_2O_3$, TiO, and $ZrO_2$ with depth in the coarse and fine silt fractions from the seven profiles studied.

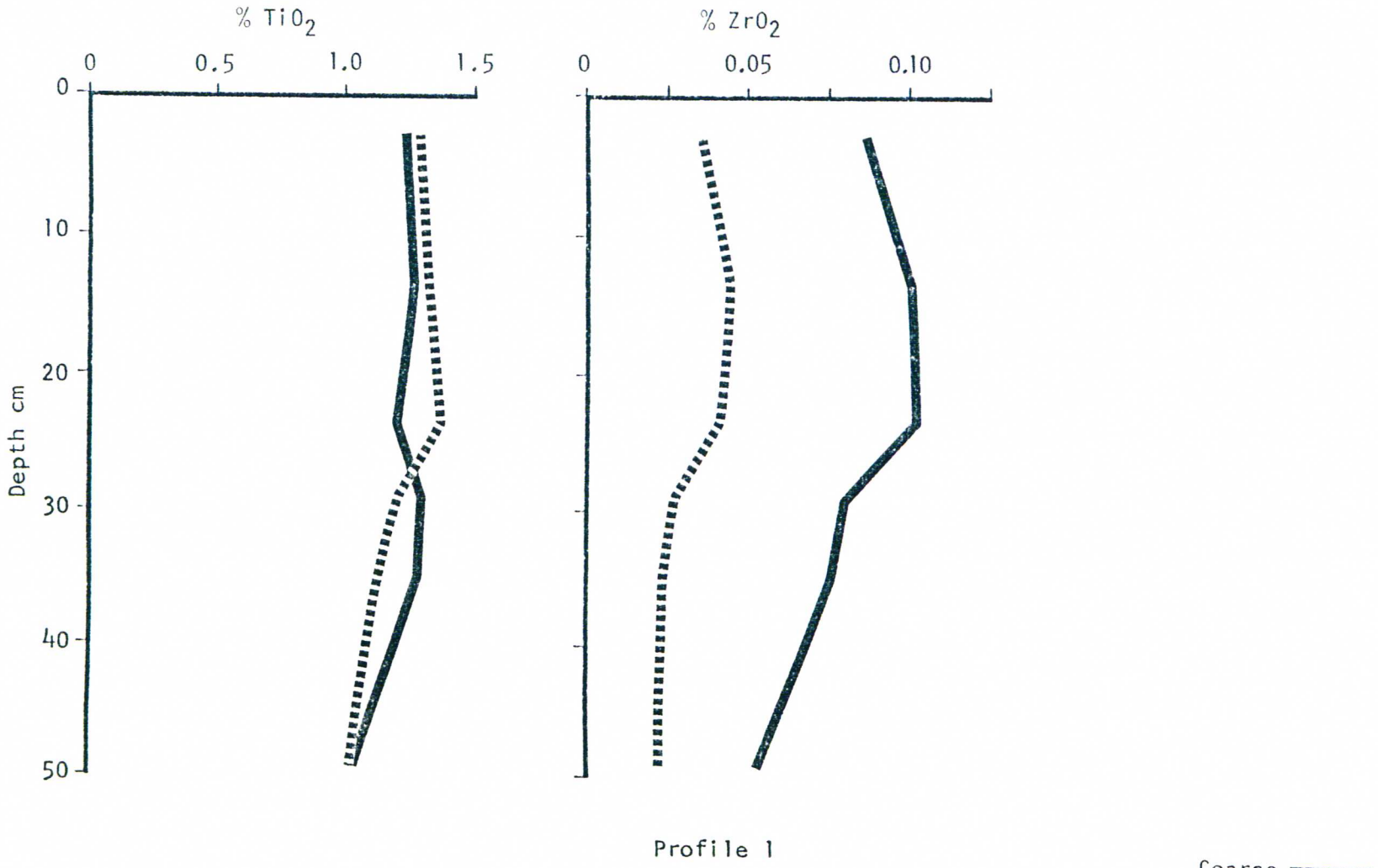



Figure 9. (continued)

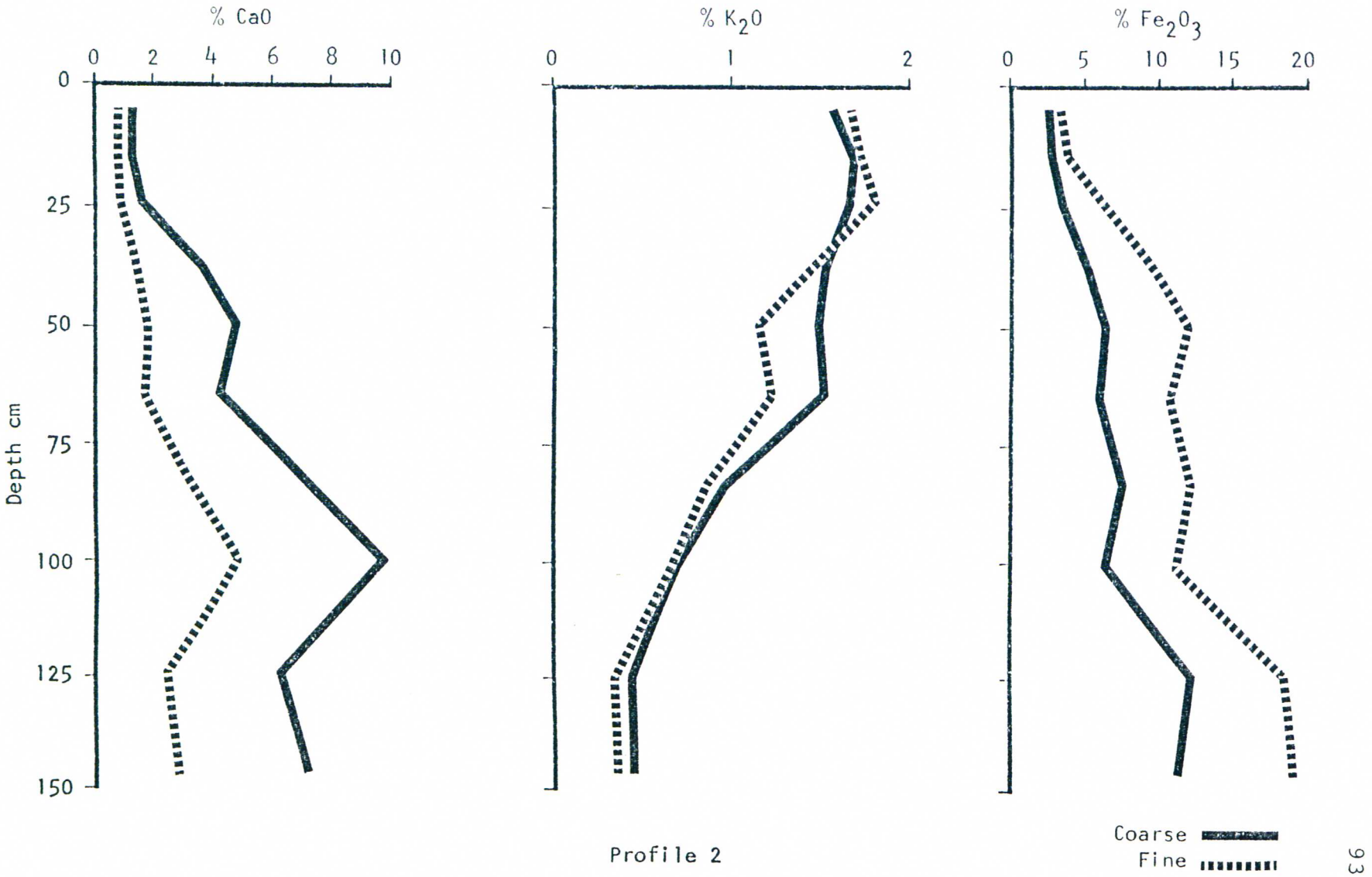



Figure 9. (continued)

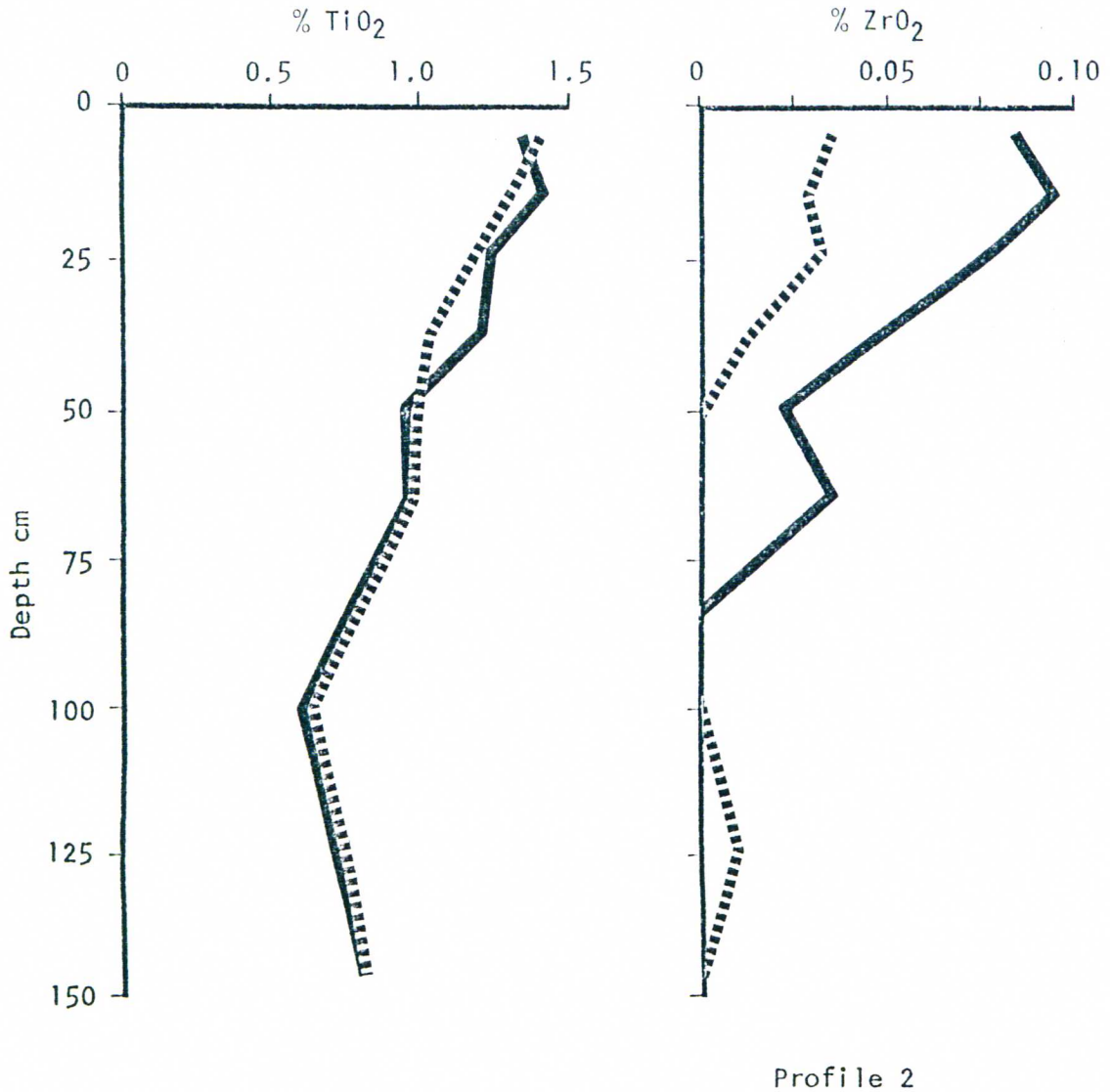



Figure 9. (continued)

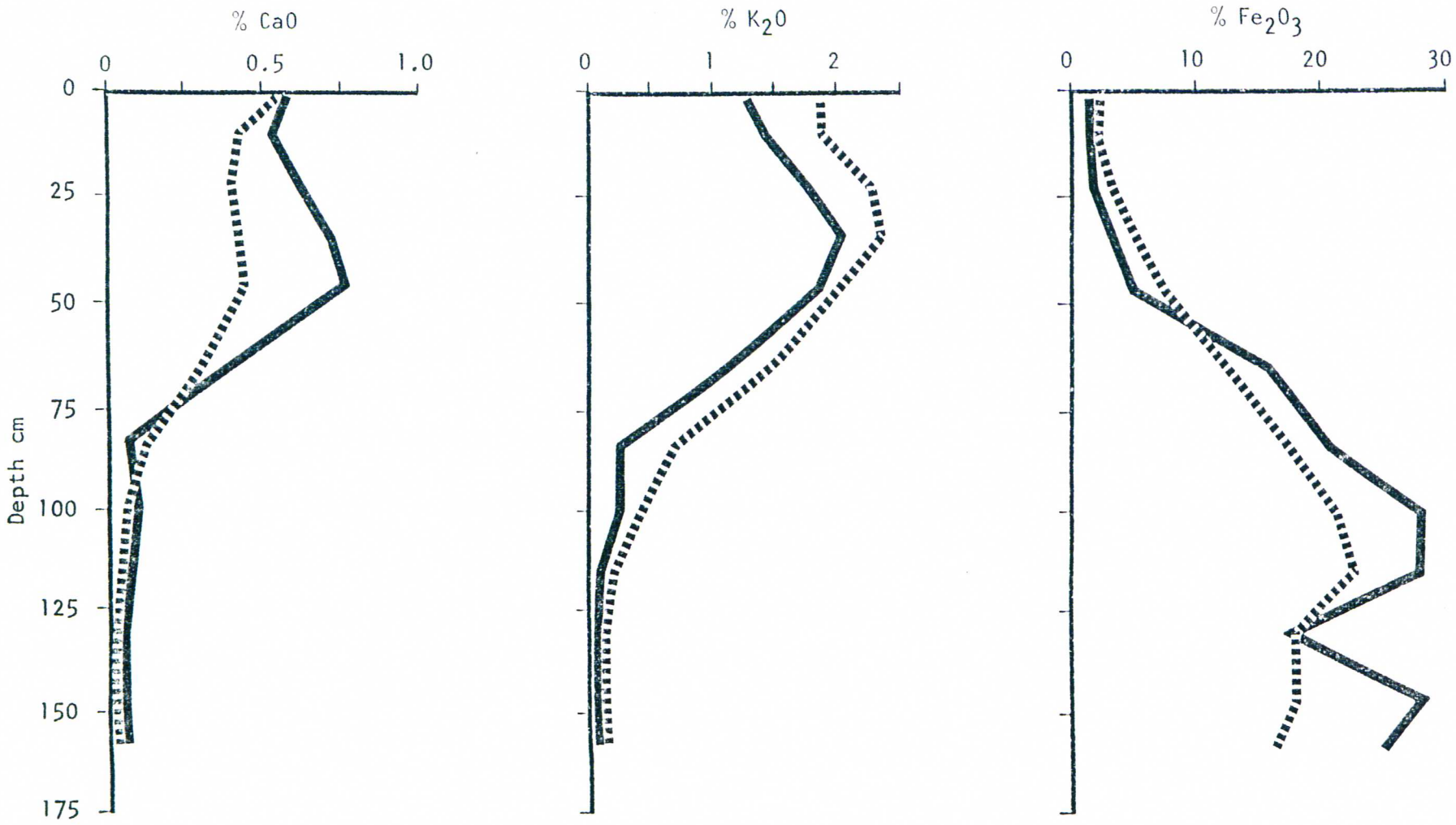



Figure 9. (continued)

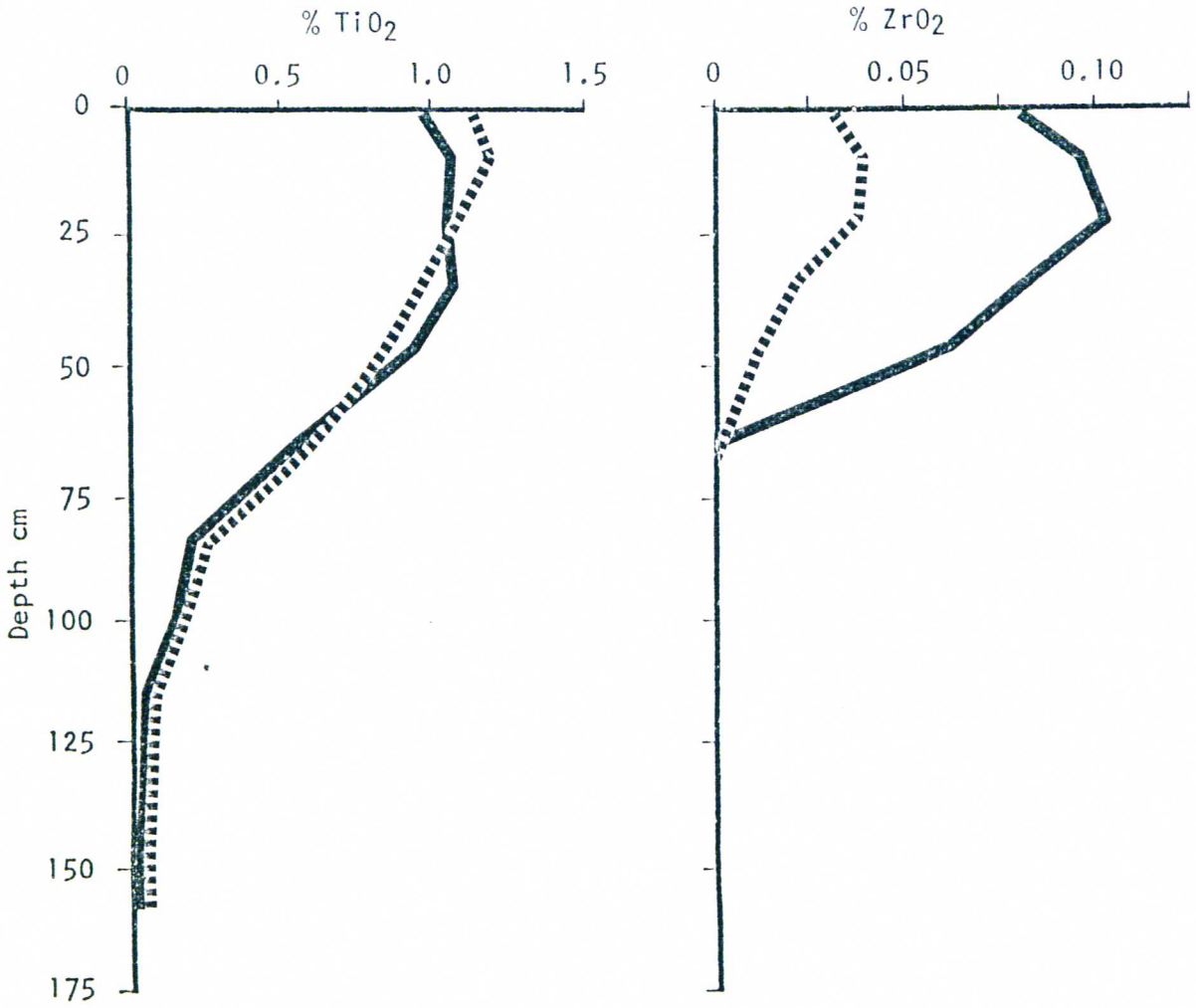



Figure 9. (continued)

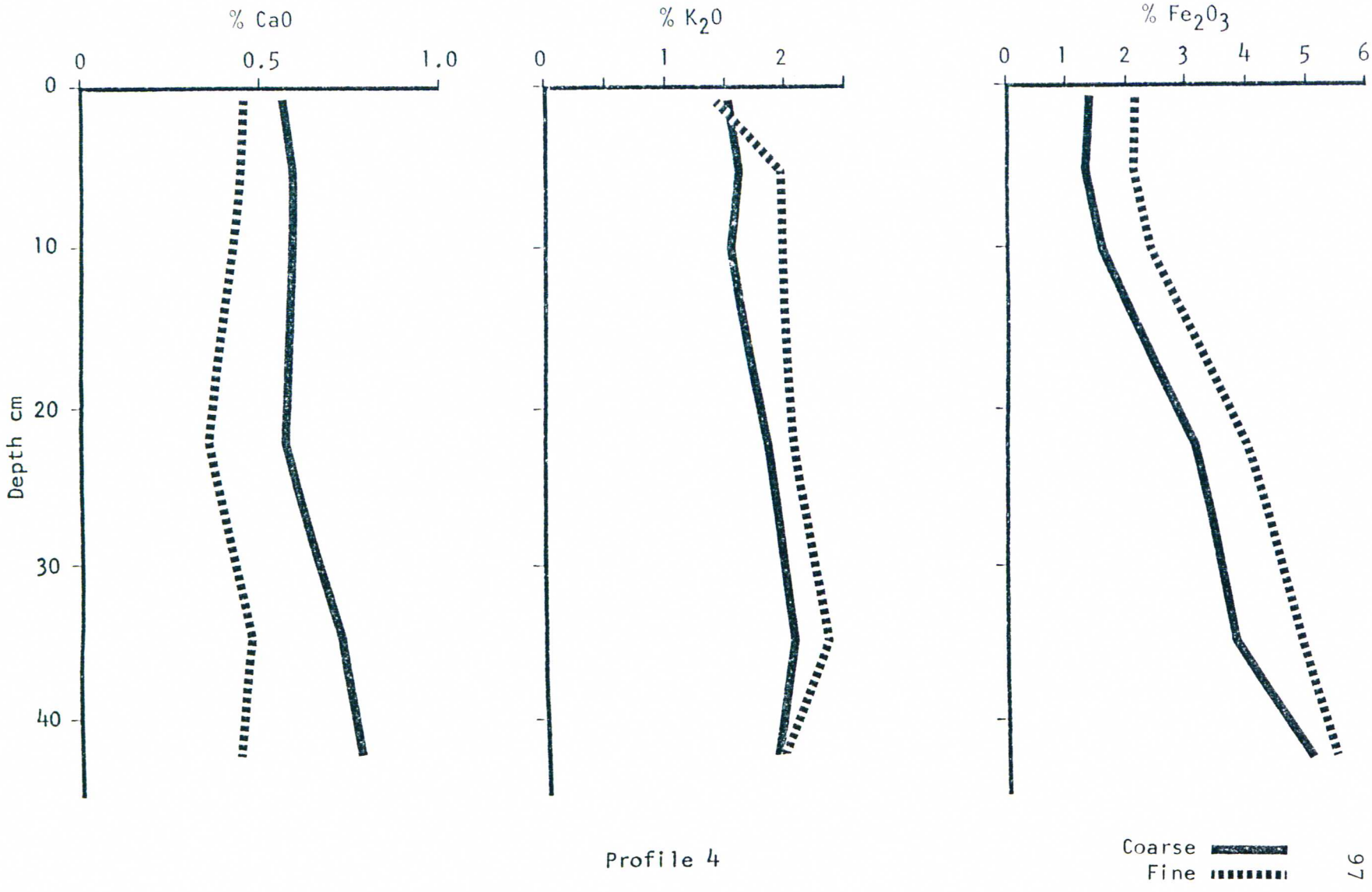



Figure 9. (continued)

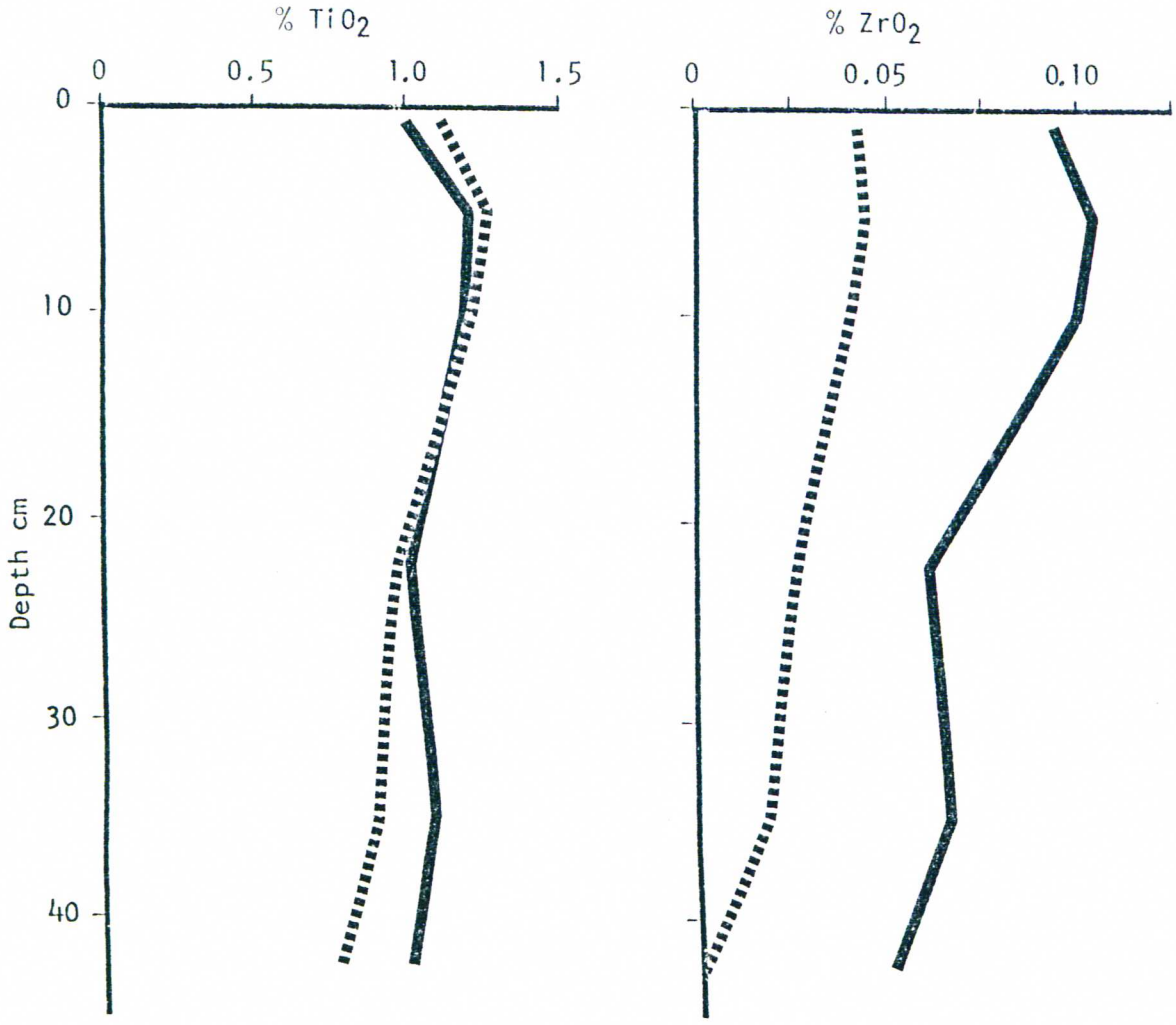



Figure 9. (continued)

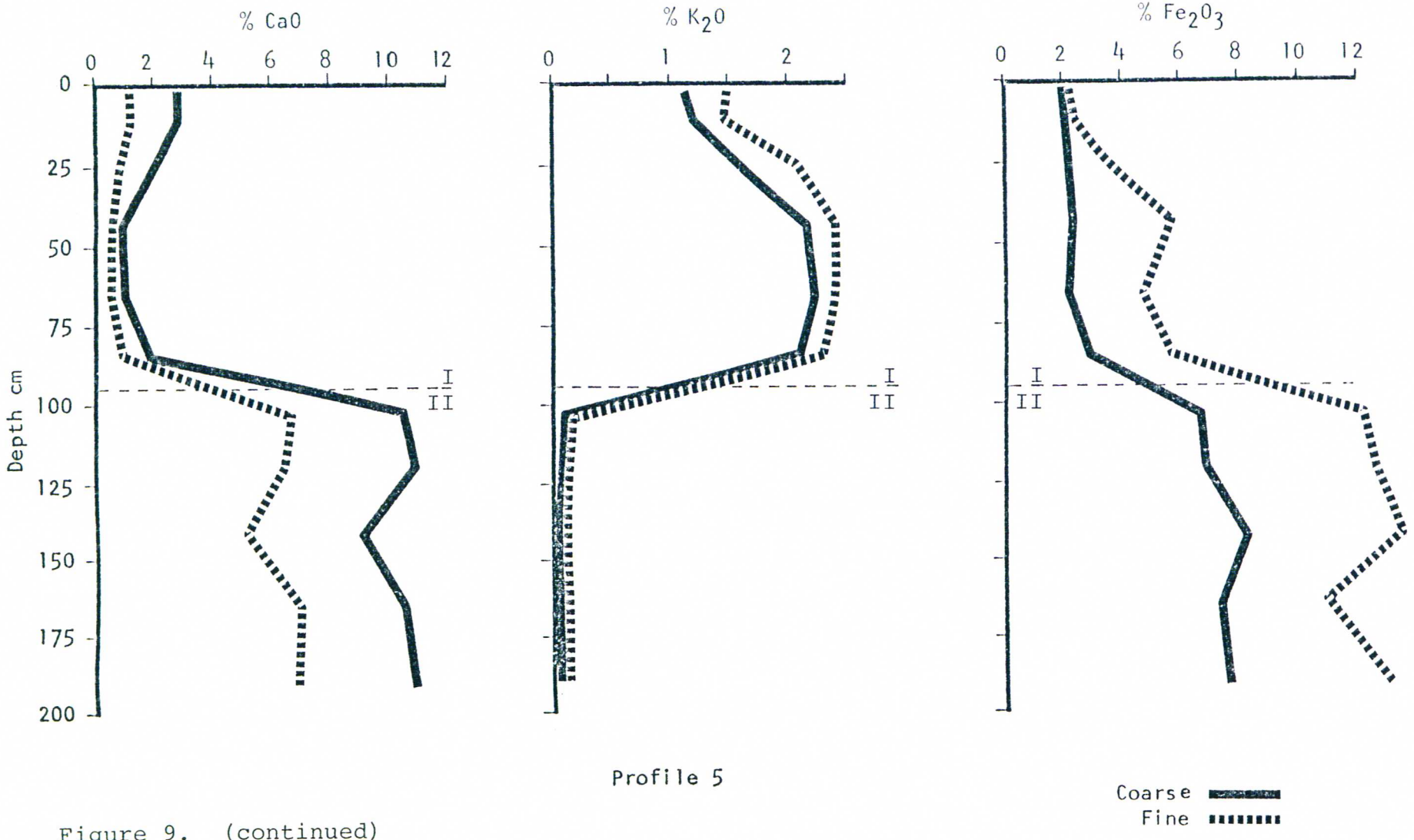
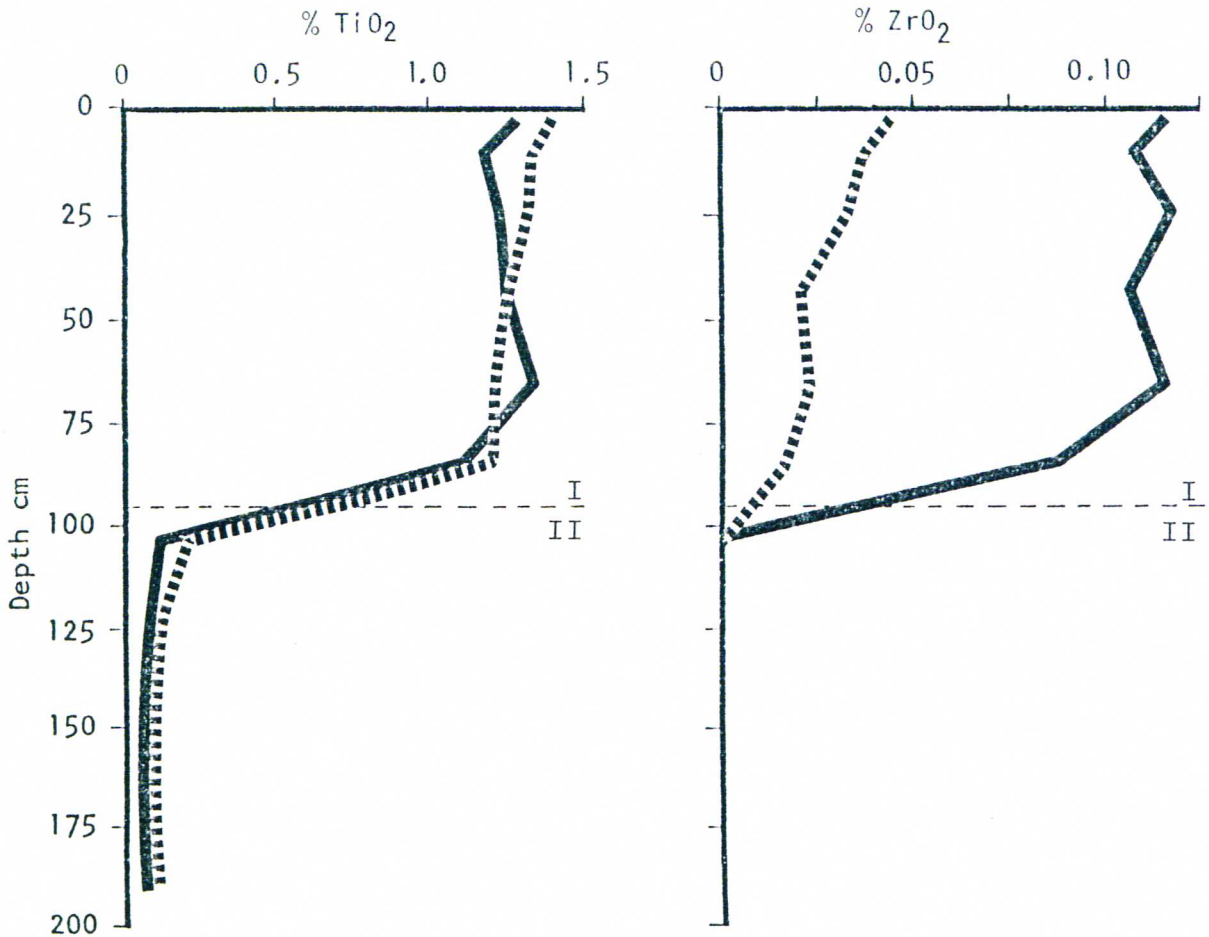



Figure 9. (continued)




Profile 5

Coarse
Fine

Figure 9. (continued)

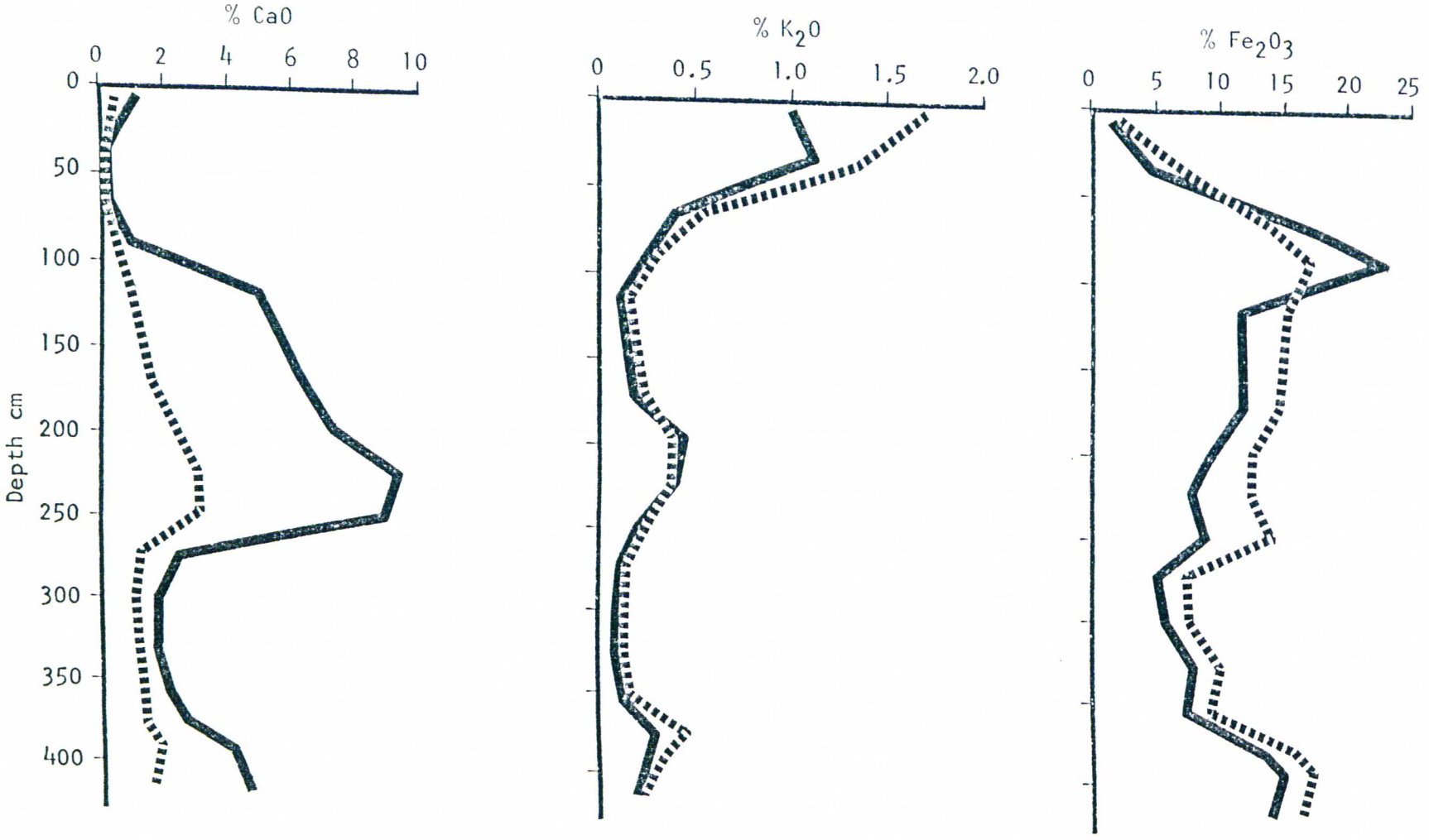



Figure 9. (continued)

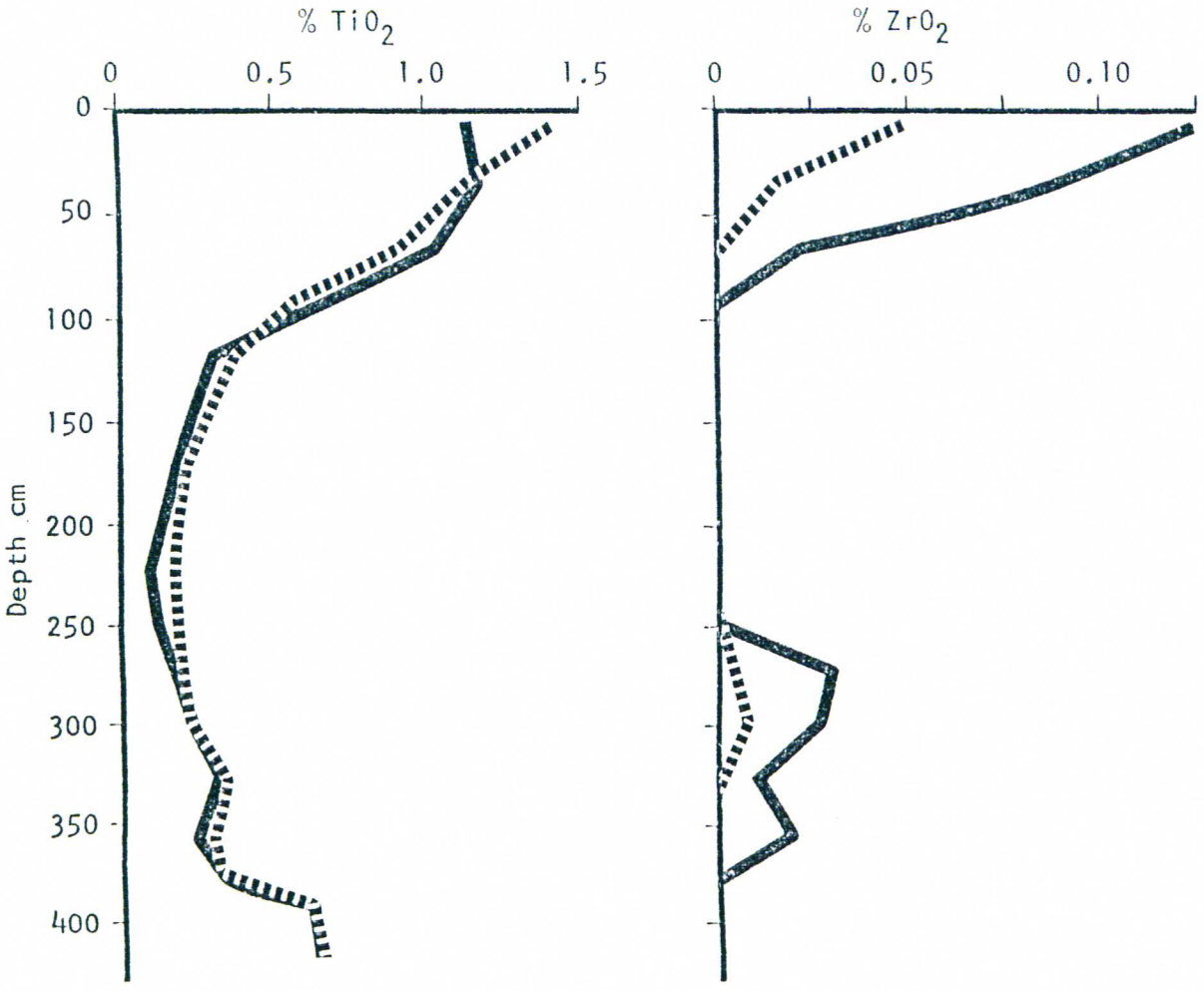



Figure 9. (continued)

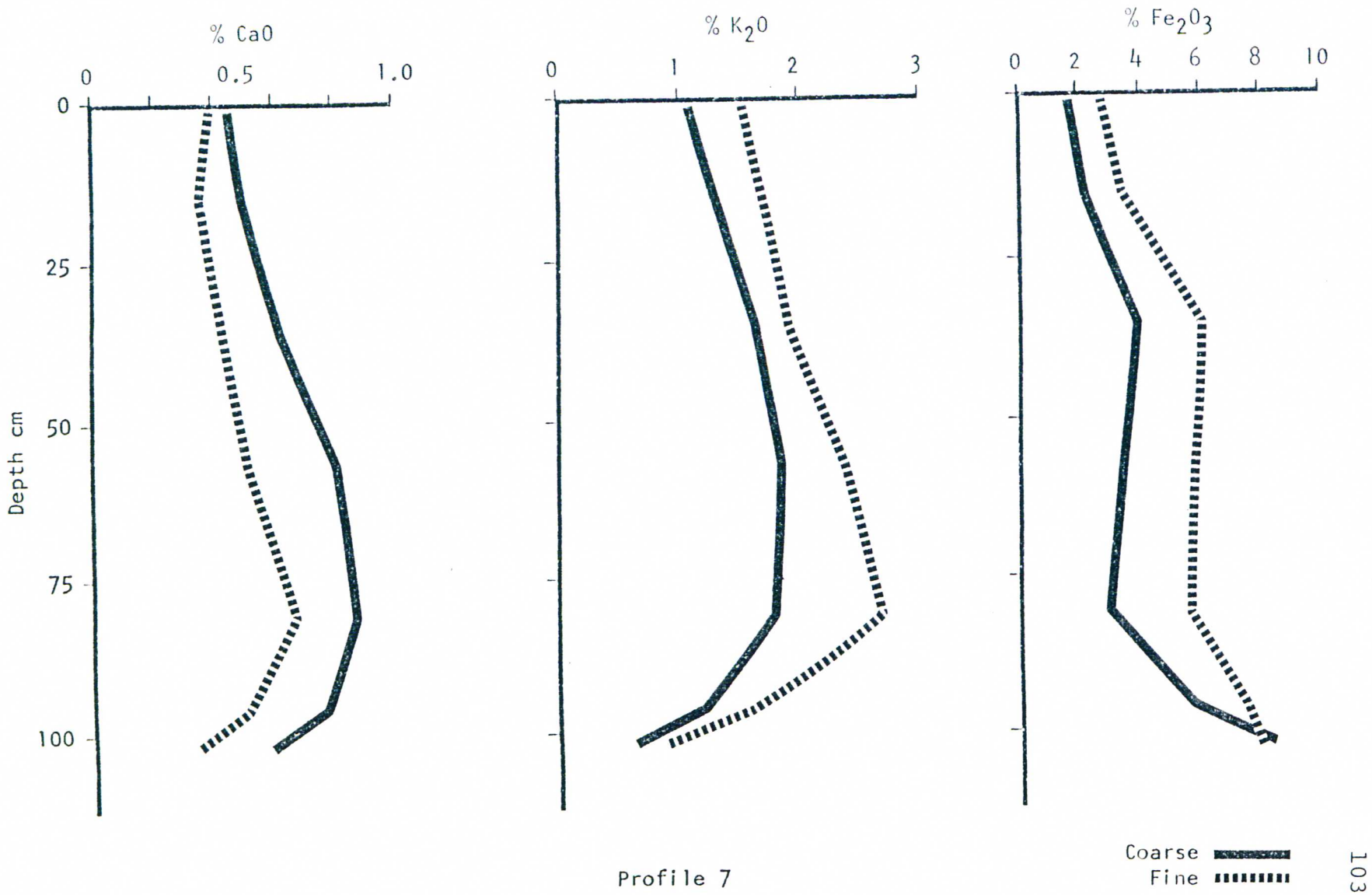



Figure 9. (continued)

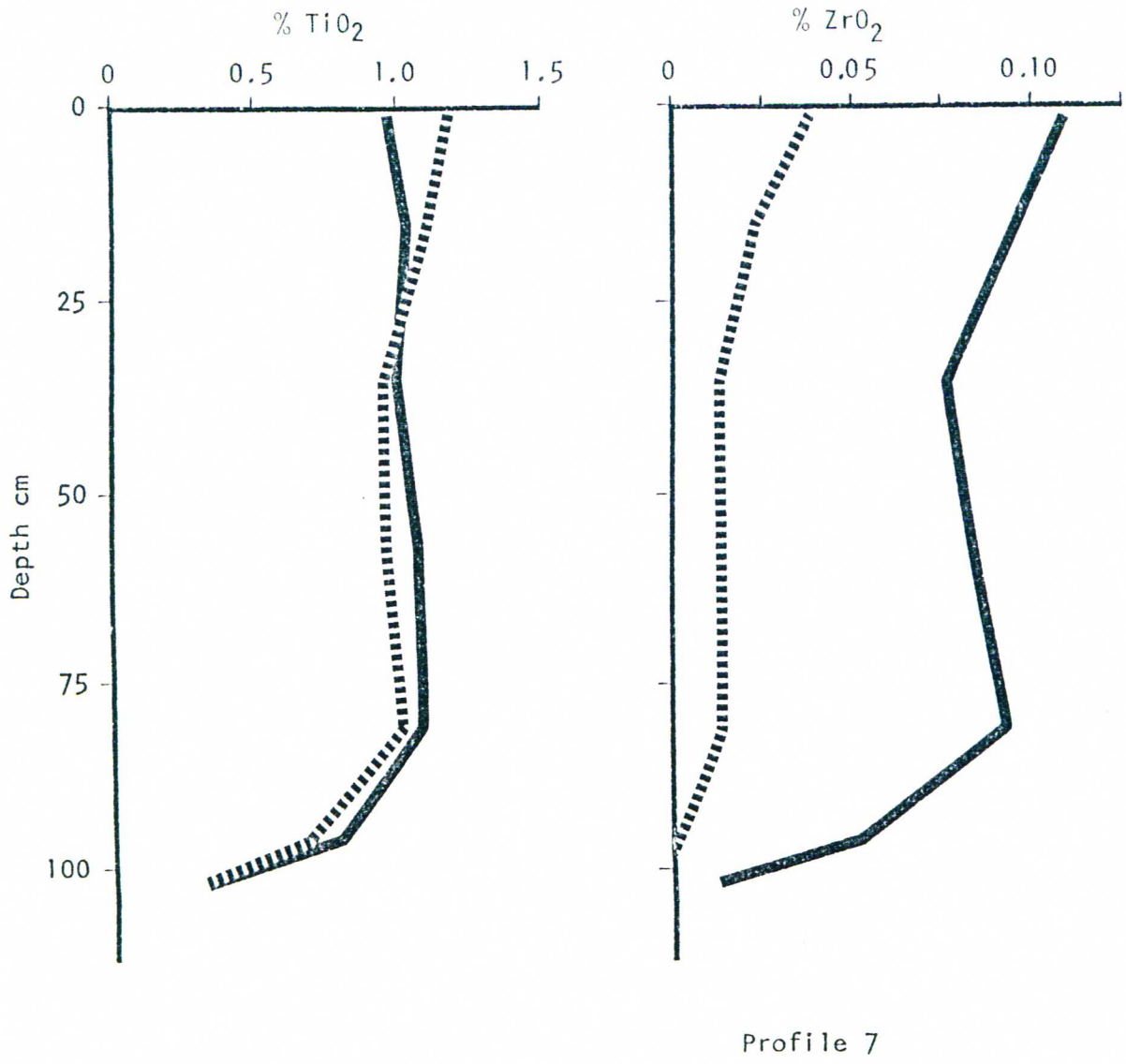



Figure 9. (continued)

these profiles, the trends are not strongly expressed. Jones et al. (1967) have shown that the $Fe_2O_3$ content of silts is a sensitive indicator of weathering in less highly weathered soils. This is clearly demonstrated in profile 4 which shows a steady increase in percent $Fe_2O_3$ with depth in both of the silt fractions.

The weatherable elements in profile 7 show a trend of increasing levels with depth which is more distinct than in profiles 1 or 4. Calcium and potassium values are approximately the same as those in profile 4. Titanium and zirconium values are also similar to those of the other two serpentine profiles described above. Values for titanium are roughly the same for coarse and fine silt fractions, decreasing from about 1.2 percent $TiO_2$ at the surface to about 0.9 percent $TiO_2$ deeper in the profile. Levels of $ZrO_2$ are consistently higher in the coarse silt fraction than in the fine silt. This is consistent with the reports of other workers (Alexander et al., 1962; Beavers et al., 1963; Chapman & Horn, 1968; Foss et al., 1978; Foss & Rust, 1968). In profiles 1, 4, and 7 $ZrO_2$ levels in the coarse silt fraction decrease with depth from about 0.10 percent near the surface to about 0.05 percent deeper in the profile. Levels in the fine silt fraction drop similarly from about 0.04 percent to about 0.01 percent. In the first few centimeters above bedrock in profile 7, coarse silt $ZrO_2$ levels dropped to .015 percent and fine silt levels were non-detectable. These values are generally lower than

those reported by other workers. This is probably the result of zircon occurring more commonly in silicic rocks while the parent material of these soils is mafic or ultramafic (Hurlbut & Klein, 1977).

In profile 5, which has developed in loess over residuum, weathering trends similar to those previously described occur in the silt cap, with the exception that there is a decrease in percent CaO to a depth of about 45 cm. This may be the result of a difference in the nature of the loess which was most recently deposited on this site. An alternate explanation may be the physical weathering of protruding Ca-rich boulders, common at this site, which would result in the addition of Ca-rich material to the soil surface. Below the lithologic discontinuity, CaO and $Fe_2O_3$ levels increased markedly while $TiO_2$ and $K_2O$ dropped to very low levels. Values for $ZrO_2$ dropped below detectable levels for both coarse and fine silt. Values below the discontinuity are fairly constant and no obvious trends are demonstrated, indicating that there has been little differential weathering of this zone.

Profile 6, which was sampled to a depth of over 4 meters, shows rather large decreases in $ZrO_2$ and $TiO_2$ with depth in the upper meter of soil. Correspondingly, large increases in $Fe_2O_3$ also occur to this depth. These trends in themselves would be best interpreted as evidence of a greater degree of weathering in the surface horizons, with a decrease in weathering with depth. A complicating factor, however, is

the fact that the $K_2O$ levels also decreased with depth to about one meter. There are two possible explanations for the higher potassium values near the surface.

One explanation might be the presence of resistant K-bearing minerals in the parent material. Springer (1948) has shown that in the early weathering stages of loess, there is an increase in K over Ca due to the slightly greater resistance to weathering of K feldspars as compared to Ca feldspars. Even if K feldspar was present in the parent material, the present soil environment would result in the rapid decomposition of this mineral. The only K-bearing rock forming mineral which is resistant to weathering is muscovite. Analyses of Harford County amphibolites, however, reveal the presence of neither muscovite nor K feldspars (Southwick, 1969). Therefore, this hypothesis of the concentration of resistant K-bearing minerals does not appear to be viable.

The alternative explanation is that additions of K-bearing minerals from another source have been made to this site. Field examinations of nearby areas reveal soils with thick silty mantles overlying horizons high in clay and very similar to the B2t horizon of profile 6. This information, as well as the loess occurrence in profile 5 and the other reports of loess in Harford County, suggest that the additions sustained by profile 6 were eolian in origin. The additions may have occurred during a single period of deposition or more gradually over a longer period of time. In either case,

the shallow thickness of the deposit in conjunction with frost action and other mixing processes have resulted in a diffuse boundary between the overlying and underlying materials. This explanation would also account for the rapid decreases in $ZrO_2$ and $TiO_2$ levels so far above bedrock. Significant variations in elemental content deeper in the profile probably reflect variations in the chemical and mineralogical content of the parent rock or differential weathering.

Profile 2 presents a similar situation in Montgomery County. The parent rock is diabase, which, according to analyses reported by Fisher (1964), contains about 0.96 percent $K_2O$, no muscovite, and approximately 2 percent biotite. The levels of $K_2O$ in the silt fraction deep in the profile is 0.4 percent thus indicating that much of the potassium is lost from parent material near the weathering front. Levels of $K_2O$ increase steadily toward the surface where they are approximately 1.6 percent. This suggests that additions of material higher in $K_2O$ have been made to this site.

Much of the surrounding area contains soils formed from Wissahickon materials which are very high in muscovite. It is possible that additions to site 2 may have been of a more local nature and do not necessitate periglacial loess deposition. Calculations indicate that roughly 5 to 10 cm of muscovitic material would have to be incorporated into the upper meter of soil to raise values of $K_2O$ in the C horizon to that of those in the A and B horizons.

Profile 3, which was the deepest serpentinite-derived soil, may also have been subject to eolian additions. While trends for levels of $Fe_2O_3$, $ZrO_2$, and $TiO_2$ are not unexpected, values for both CaO and $K_2O$ are much greater in the upper 70 cm of the profile than below this level. Potassium-bearing biotite or phlogopite may be associated with serpentine but both are relatively easily weathered minerals and could not account for these higher $K_2O$ levels. Additions to the surface are the only viable explanation. The decreasing trends with depth for CaO and $K_2O$ in the upper 35 to 45 cm of this profile suggest that some weathering of these Ca and K-bearing minerals has occurred since the material was incorporated into the profile.

Mineralogy

Interpretations of x-ray diffraction data are presented in Table 8. Serpentine minerals predominate in the parent rock of profile 1, and are accompanied by substantial amounts of chlorite. In the soil, however, serpentine occurs at greatly reduced levels and is present almost exclusively in the fine silt fraction. Chlorite and vermiculite, much of which is interstratified, are the dominant minerals in the < 5 μm soil fractions. Chlorite is the most likely precursor of the vermiculite (Coffman & Fanning, 1975; Ross, 1969; 1975; Ross & Kodama, 1974). The increase of vermiculite with decreasing particle size in conjunction with generally higher levels

Table 8. Semi-quantitative interpretation of X-ray diffraction patterns of fine silt (2-5 μm), coarse clay (0.2-2 μm), and fine clay (< 0.2 μm) fractions from selected horizons of the profiles studied.

| Lab No. | Depth cm | Size Fraction μm | Relative Quantity* of Minerals§ Present | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fl | Qr | Mi | Vr | Sm | Chl | Kl | Serp. | Amph | Other | Remarks |
| Profile 1 | | | | | | | | | | | | | |
| 6203 | 6-21 | 2-5 | x | xx | x | x | - | xxx | - | x | - | - | |
| | | 0.2-2 | - | x | - | xx | - | xxxx | - | - | - | x | Reg.IS Chl-Vr, ½ Chl IS w/Vr |
| | | <0.2 | - | - | - | xxxx | x | xx | - | - | - | - | All IS |
| 6206 | 32-38 | 2-5 | x | xx | x | xx | - | xxx | - | x | - | x | Reg. IS Chl-Vr |
| | | 0.2-2 | | x | - | xxx | - | xxx | - | - | - | x | Reg. IS Chl-Vr, ½ Chl IS w/Vr |
| | | <0.2 | | - | - | xxxx | x | xx | - | - | - | - | All IS |
| 6208 | 38-60(c) | 2-5 | x | x | x | xx | - | xxx | - | xx | - | x | Reg. IS Chl-Vr |
| | | 0.2-2 | | x | x | xxx | ? | xxx | - | x | - | - | Partially IS Vr-Chl |
| | | <0.2 | | - | - | xxxx | xx | xx | - | - | - | - | All IS |
| Rock Sample | | | | | | | | xx | | xxxx | | | |
| Profile 2 | | | | | | | | | | | | | |
| 6210 | 0-11 | 2-5 | xx | xx | xx | xxx | - | - | x | - | x | | |
| | | 0.2-2 | - | ? | x | xxx | - | - | xx | - | - | | |
| | | <0.2 | - | - | - | xxx | xx | - | xx | - | - | | V. poor. cryst. |
| 6213 | 29-45 | 2-5 | x | xx | x | xxx | xx | - | x | - | - | | |
| | | 0.2-2 | - | - | - | xxxx | x | - | x | - | - | | |
| | | <0.2 | - | - | - | xxx | xxx | - | - | - | - | | V. poor. cryst. |
| 6216 | 75-92 | 2-5 | ? | x | - | xxxx | xx | - | x | - | - | | |
| | | 0.2-2 | - | - | - | xxxx | x | - | x | - | - | | |
| | | <0.2 | - | - | - | xxx | xxx | - | - | - | - | | Extr. poor. cryst. |
| 6219 | 138-154 | 2-5 | ? | - | - | xxxx | x | - | x | - | - | | Some Vr IS w/Sm |
| | | 0.2-2 | - | - | - | xxx | xx | - | ? | - | - | | Mostly IS |
| | | <0.2 | - | - | - | xxx | xxx | - | - | - | - | | Extr. poor. cryst. |
| Rock Sample | | | xxx | | | | | | | | | xxx | Pyroxene |

Table 8 (continued)

| Lab No. | Depth cm | Size Fraction µm | Relative Quantity* of Minerals§ Present | | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fl | Qr | Mi | Vr | Sm | Chl | Kl | Serp. | Amph | Other | |
| Profile 3 | | | | | | | | | | | | | |
| 6221 | 4-16 | 2-5 | xx | xx | xx | xx | - | x | - | xxx | | | All Chl IS |
| | | 0.2-2 | - | xx | x | xxx | - | xx | - | xx | | | ½Chl + ½Vr IS |
| | | <0.2 | - | - | - | x | xxx | xxx | - | - | | | All IS |
| 6222 | 16-28 | 2-5 | x | xx | xx | xx | - | x | - | xxx | | | |
| | | 0.2-2 | x | xx | x | xxx | x | xx | - | xx | | | Most Chl IS |
| | | <0.2 | - | - | x | x | xxx | xx | - | - | | | All Chl IS |
| 6224 | 40-53 | 2-5 | x | x | xx | xx | - | x | - | xxx | | | |
| | | 0.2-2 | - | x | x | xx | x | xx | - | xxx | | | ½Chl IS |
| | | <0.2 | - | - | - | - | xxxx | xx | - | - | | | ½Sm IS w/Chl |
| 6226 | 75-91 | 2-5 | x | x | - | x | x | - | - | xxxx | | | |
| | | 0.2-2 | - | - | - | x | xxx | xx | - | xx | | | |
| | | <0.2 | - | - | - | - | xxxx | x | - | x | | | |
| 6228 | 107-123 | 2-5 | - | x | - | x | x | - | - | xxxx | | | |
| | | 0.2-2 | - | - | - | x | xx | x | - | xxx | | | Vr-Chl-Sm IS |
| | | <0.2 | - | - | - | - | xxxx | x | - | - | | | |
| 6229 | 123-139 | 2-5 | - | - | - | - | x | - | - | xxxx | | | |
| | | 0.2-2 | - | - | - | - | xxx | x | - | xxx | | | Chl IS w/Vr |
| | | <0.2 | - | - | - | - | xxxx | x | - | - | | | Chl IS w/Sm |
| 6231 | 155-170 | 2-5 | - | - | - | - | x | - | - | xxxx | | | |
| | | 0.2-2 | - | - | - | x | xx | x | - | xxxx | | | Chl IS |
| | | <0.2 | - | - | - | - | xxxx | x | - | x | | | |
| Rock Sample | | | | | | | | | | xxxx | | | |
| Profile 4 | | | | | | | | | | | | | |
| 6233 | 2-8 | 2-5 | x | x | x | xx | ? | x | - | xxx | - | x | Talc |
| | | 0.2-2 | - | x | - | xx | x | xx | - | xx | - | xx | Talc; ½Chl + all Vr IS |
| | | <0.2 | - | - | - | xxx | xx | xxx | - | - | - | xx | Talc; some IS of all minerals |

Table 8 (continued)

| Lab No. | Depth cm | Size Fraction µm | Relative Quantity* of Minerals§ Present | | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fl | Qr | Mi | Vr | Sm | Chl | Kl | Serp. | Amph | Other | |
| Profile 4 (continued) | | | | | | | | | | | | | |
| 6236 | 26-43 | 2-5 | x | x | xx | xx | x | x | - | xxx | - | x | Talc |
| | | 0.2-2 | - | x | x | xxx | x | xx | - | xxx | - | xx | Talc |
| | | <0.2 | - | - | - | xxx | xx | xx | - | - | - | - | Mostly IS |
| 6237 | 41-43 | 2-5 | x | x | xx | x | ? | x | - | xxxx | - | x | Talc |
| | | 0.2-2 | - | x | x | xx | x | xx | - | xxx | - | xx | Talc |
| | | <0.2 | - | - | | xxx | xxx | xx | - | - | - | - | |
| Profile 5 | | | | | | | | | | | | | |
| 6239 | 6-16 | 2-5 | x | xxx | xx | xx | - | xx | xx | - | xx | ? | Talc |
| | | 0.2-2 | x | xx | - | xxx | - | xx | xx | - | x | x | Talc; some Chl-Vr IS |
| | | <0.2 | - | - | - | xxx | x | xx | xx | - | - | - | All Chl-Vr IS |
| 6242 | 55-75 | 2-5 | x | xx | xx | xxx | - | ? | xx | - | ? | - | |
| | | 0.2-2 | - | xx | xx | xxx | - | ? | xxx | - | - | - | |
| | | <0.2 | - | - | x | xxx | xx | x | xx | - | - | - | Sm+Vr IS |
| 6246 | 130-155 | 2-5 | - | - | - | - | x | - | xx | - | - | xxxx | Reg. IS Chl-Vr |
| | | 0.2-2 | - | - | - | x | x | - | xx | - | - | xxx | Reg. IS Chl-Vr |
| | | <0.2 | - | - | - | xx | xx | xx | xx | - | - | - | All Vr-Sm-Chl IS; V. poor. cryst. |
| Rock Sample | | | xx | | | | | xxx | | | xxx | | |
| Profile 6 | | | | | | | | | | | | | |
| 6249 | 0-18 | 2-5 | x | xx | xx | xx | - | xx | xx | - | - | - | |
| | | 0.2-2 | - | x | x | xxx | x | x | xxx | - | - | - | ½ Vr + all Chl IS |
| | | <0.2 | - | - | - | xx | xx | x | xx | - | - | - | IS Vr-Sm-Chl; poor.cryst. |
| 6251 | 55-78 | 2-5 | - | xx | xx | xx | - | - | xxx | - | - | - | |
| | | 0.2-2 | - | x | - | xxx | xx | ? | xxx | - | - | - | Chl IS |
| | | <0.2 | - | - | - | x | xxx | ? | xxx | - | - | - | Chl IS |

Table 8 (continued)

| Lab No. | Depth cm | Size Fraction µm | Relative Quantity* of Minerals§ Present | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fl | Qr | Mi | Vr | Sm | Chl | Kl | Serp. | Amph | Other | |
| Profile 6 (continued) | | | | | | | | | | | | | |
| 6253 | 103-130 | 2-5 | - | x | - | - | xx | x | xxx | - | - | - | Chl IS |
| | | 0.2-2 | - | x | - | x | xxx | x | xxx | - | - | - | Chl Is |
| | | <0.2 | - | - | - | - | xxx | x | xxx | - | - | - | Chl IS |
| 6256 | 183-211 | 2-5 | - | - | - | - | xxx | - | xx | - | - | xxx | Reg. IS Chl-Vr |
| | | 0.2-2 | - | - | - | - | xxxx | - | xx | - | - | xx | Reg. IS Chl-Vr |
| | | <0.2 | - | - | - | - | xxxx | - | xx | - | - | - | |
| 6258 | 236-260 | 2-5 | - | - | - | - | xx | - | xxx | - | - | xx | Reg. IS Chl-Vr |
| | | 0.2-2 | - | - | - | - | xxxx | - | xx | - | - | x | Reg. IS Chl-Vr; low cryst. |
| | | <0.2 | - | - | - | - | xxxx | - | xx | - | - | - | V. poor. cryst. |
| 6260 | 285-310 | 2-5 | - | - | - | x | xxx | - | xxx | - | - | xx | Reg. IS Chl-Vr |
| | | 0.2-2 | - | - | - | xx | xxx | - | xxx | - | - | x | Reg. IS Chl-Vr; low cryst. |
| | | <0.2 | - | - | - | - | xxx | x | xxx | - | - | - | Sm-Chl IS; poor.cryst. |
| 6262 | 346-371 | 2-5 | - | - | - | xx | xxx | - | xxx | - | - | x | Reg. IS Chl-Vr |
| | | 0.2-2 | - | - | - | xx | xxxx | - | xx | - | - | - | |
| | | <0.2 | - | - | - | - | xxxx | - | xx | - | - | - | |
| 6265 | 400-430 | 2-5 | - | - | - | x | xx | - | xxxx | - | x | - | |
| | | 0.2-2 | - | - | - | - | xxxx | - | - | - | - | - | V. poor. cryst. |
| | | <0.2 | - | - | - | - | xxxx | - | ? | - | - | - | V. poor. cryst. |
| Rock Sample Profile 7 | | | - | - | - | - | - | - | - | - | xxxx | - | Mainly hornblende |
| 6266 | 0-3 | 2-5 | x | xx | - | xx | - | x | - | xxx | - | xx | Talc |
| | | 0.2-2 | - | xx | - | xx | - | x | - | xxx | - | xx | Talc |
| | | <0.2 | - | - | - | xxx | x | x | - | - | - | - | All IS; v.poor.cryst. |
| 6268 | 27-43 | 2-5 | x | x | xx | xxx | | xx | - | xxx | - | x | Talc |
| | | 0.2-2 | x | x | x | xxx | x | xx | - | xx | - | xx | Talc |
| | | <0.2 | - | - | - | xxx | xxx | xx | - | - | - | - | All IS; extr. poor. cryst. |

Table 8 (continued)

| Lab No. | Depth cm | Size Fraction µm | Relative Quantity* of Minerals§ Present | | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fl | Qr | Mi | Vr | Sm | Chl | Kl | Serp. | Amph | Other | |
| Profile 7 (continued) | | | | | | | | | | | | | |
| 6270 | 70-92 | 2-5 | xx | x | xx | xx | - | xx | - | xxx | - | x | Talc |
| | | 0.2-2 | x | x | x | xxx | x | xx | - | xx | - | x | Talc |
| | | <0.2 | - | - | x | xxx | xxx | xx | - | - | - | - | ½Chl IS w/Vr + Sm ; poor. cryst. |
| 6272 | 100-104 | 2-5 | - | - | - | xxx | - | x | - | xxx | - | xx | Talc |
| | | 0.2-2 | - | - | - | xxx | x | xx | - | xxx | - | xx | Talc |
| | | <0.2 | - | - | - | xxx | xxx | xx | - | - | - | - | All IS; poor. cryst. |
| Rock Sample | | | - | - | - | - | - | xx | - | xxxx | - | - | |

* x - low amount, <10%
xx - moderate amount, 10-30%
xxx - high amount, 30-70%
xxxx - dominant mineral, >70%

§ Abbreviations: Fl - feldspar; Qr - quartz; Mi - mica; Vr - vermiculite; Sm - smectite; Chl - chlorite; Kl - kaolinite; Serp - Serpentine; Amph - amphibole.

of chlorite in the larger particle size fractions further suggests that vermiculite is forming at the expense of chlorite.

While some small amounts of smectite have formed from serpentine in the fine clay, the occurrence of no other minerals in the soil can be traced directly to the weathering of serpentine (Wildman et al., 1968; 1971). It is possible that some dioctahedral vermiculite in the fine clay fraction may have been synthesized from weathering products but reports of these occurrences are scant (Barshad & Kishk, 1969). The report of Cleaves et al. (1974) stated that dissolved material from a serpentine watershed was much higher than for some other rock types. This suggests that the weathered serpentine is being removed in soluble form by percolating ground water, leaving the chlorite to accumulate residually.

The presence of small amounts of quartz, mica, and feldspar throughout the profile, while absent from the parent rock, indicates that some additions of the minerals have occurred to the site of profile 1. Small amounts of a regularly interstratified chlorite-vermiculite were observed in the fine silt and coarse clay fractions of this profile, and will be discussed later.

The mineralogy of profiles 4 and 7 is very similar and is dominated by serpentine, particularly in the $> 2$ µm fraction while vermiculite and chlorite are more abundant in the $< 2$ µm fractions. Smectite is present primarily in the fine clay fraction indicating its probable origin from serpentine

weathering products. The degree of interstratification of chlorite, vermiculite and smectite generally increases as particle size decreases. Talc, which is a metamorphic mineral commonly associated with serpentine, was present at low to moderate levels throughout the profile and was probably present in the parent rock. The presence of feldspar, quartz and mica, mainly in the 2 to 5 μm fraction, indicates that some additions of material have been made to these sites.

X-ray diffraction patterns for selected horizons of profile 3 are presented in Figure 10. It has been previously suggested that profile 3, which has formed primarily from serpentine, has received additions of eolian material. This is reflected in the presence of feldspar, mica, and quartz in the upper 90 cm of the profile. The dominance of serpentine in the 2 to 5 μm fraction throughout the profile indicates that the eolian additions were limited and did not constitute the main portion of the parent material.

The conspicuous absence of serpentine from the fine clay and the dominance of smectite in this fraction is again evidence for the formation of smectite from serpentine. In the lower half of the profile, smectite has formed in moderate to high amounts in the 0.2 to 2.0 μm fraction and is present in small amounts even in the fine silt. The increase in < 0.2 μm-sized chlorite toward the surface and a corresponding decrease in the < 0.2 μm smectite, may be the result of the formation of hydroxy interlayered smectite, sometimes called

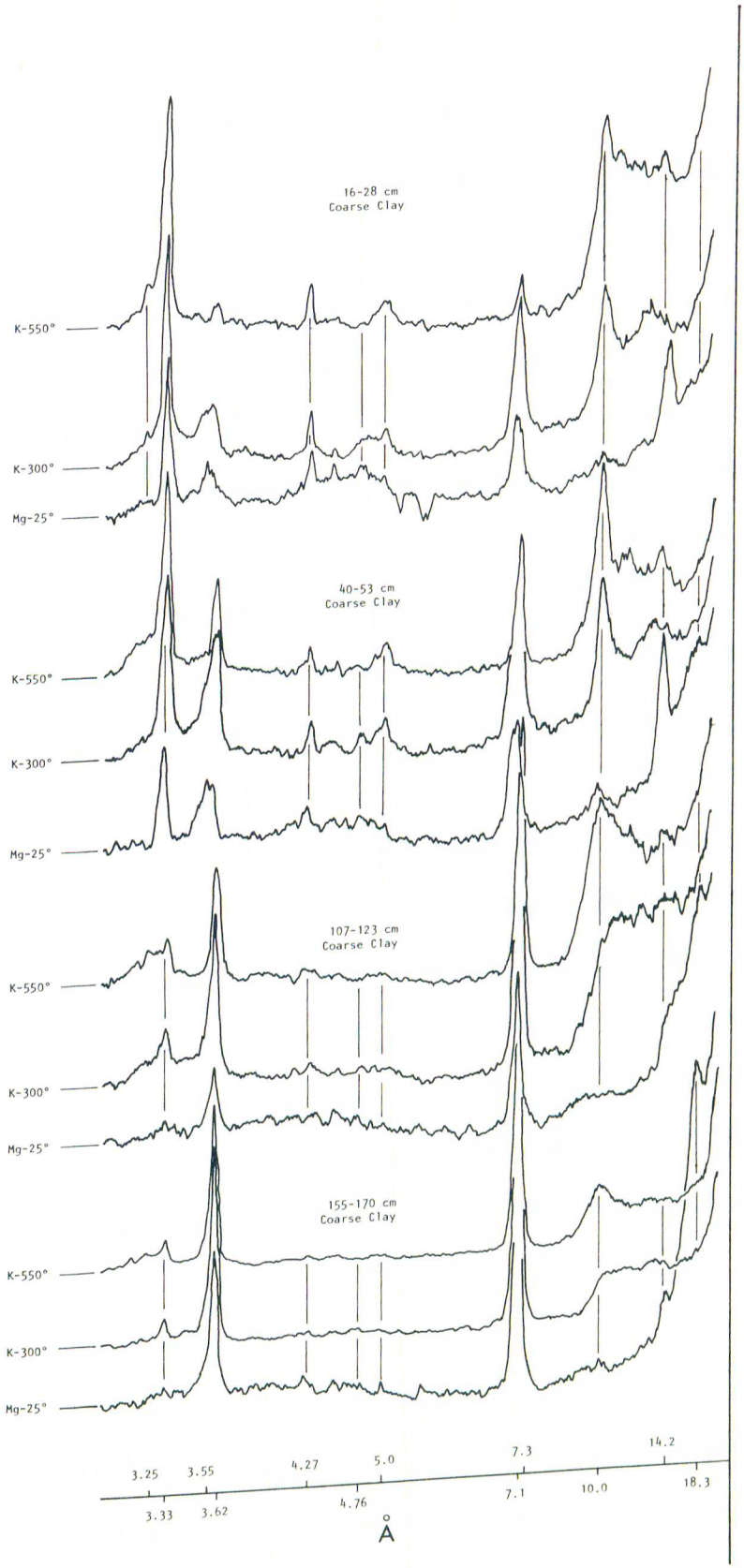



Figure 10. X-ray diffraction patterns of selected horizons from profile 3.

pedogenic chlorite (Barnhisel, 1977). These two minerals are to a large degree interstratified in the fine clay.

Vermiculite is present mainly in the upper half of the profile and is concentrated in the coarse clay and fine silt fractions. The precursor of this vermiculite might have been either chlorite which was present in the parent rock, or mica which had been added to the site and incorporated into the profile, or a combination of the two (Douglas, 1965; Post & White, 1967; Rausell-Colom et al., 1965).

According to analyses reported by Fisher (1964) the diabase of Boyds sill, which is the parent rock of profile 2, is composed of about 50 percent plagioclase feldspar and about 50 percent pyroxene, half of which is hypersthene and half of which is augite. He also reported the presence of approximately 2 percent biotite. X-ray diffraction data show that all of the pyroxene and virtually all of the feldspar is absent from the < 5 µm fraction of the soil indicating that these minerals were altered early in pedogenesis. The presence of mica, quartz, and some K feldspar in the coarser fractions of the upper portion of the profile are most likely the result of windblown additions.

While some kaolinite is present, perhaps as a weathering product of feldspar, the dominant minerals in this soil are vermiculte and smectite. Much of the vermiculite and virtually all of the smectite in the < 2 µm fractions are interstratified and poorly crystalline, while vermiculite in

the fine silt fraction is more discrete and more highly crystalline. Much of the vermiculite, particularly in the upper horizons probably has formed as an alteration product of mica, and itself may be an intermediate in the formation of smectite (Borchardt, 1977). It is difficult, however, to imagine that the high levels of expansible 2:1 minerals in the lower portions of the profile which do not appear to have received mica additions have formed by the alteration of the 2 percent biotite which was in the parent rock. This suggests that at least some of the vermiculite and smectite has formed by synthesis.

The upper meter of profile 5 has formed in loess of mixed mineralogy while the lower portion of the profile has formed from a metagabbro composed chiefly of amphibole (probably hornblende), chlorite, and plagioclase. The discontinuity in the profile is reflected by the presence of feldspar, quartz, and mica in the upper meter which is absent below the discontinuity. Vermiculite, which tends to be interstratified in the fine clay and discrete in the coarser fractions, is more prominent in the loess material than in the residuum. Chlorite and kaolinite are also present throughout the loess material. Small amounts of amphibole and talc are present only at the surface, probably the result of more recent additions.

The most striking feature in the mineralogy of this profile is the dominance of a highly crystalline regularly interstratified chlorite-vermiculite in the coarse clay and fine silt fractions of the residual material. X-ray diffraction

patterns for the IICI horizon of profile 5 are presented in Figure 11. Since the structural layers are alternately chlorite and vermiculite, the true d spacing of this mineral is 28 Å when expanded and 24 Å when collapsed. Several higher order reflections are also evident in the diffraction patterns.

Another occurrence of a regularly interstratified chlorite-vermiculite was found in the Highfield soil of Adams County, Pennsylvania (Johnson, 1964). Some researchers have artificially synthesized regularly interstratified chlorite-vermiculite by weathering a chlorite sample from the Middletown Valley in Maryland using saturated bromine water on a steam bath (Ross & Kodama, 1976). From this and other experiments, the tendency of a particular chlorite sample to weather to either a simple vermiculite or a regularly interstratified chlorite-vermiculite has been related to the Fe content of the mineral (Ross, 1969; 1975; Ross & Kodama, 1974; 1976).

According to the geologic map of Harford County (Southwick & Owens, 1968), the soil of profile 6 has formed from amphibolite. In addition, X-ray diffraction analyses of rocks found in the vicinity show them to be almost entirely hornblende. As previously mentioned, however, elemental analyses of the silt fractions indicate that there may have been some variability in the chemical or mineralogical composition of the parent rock with depth.

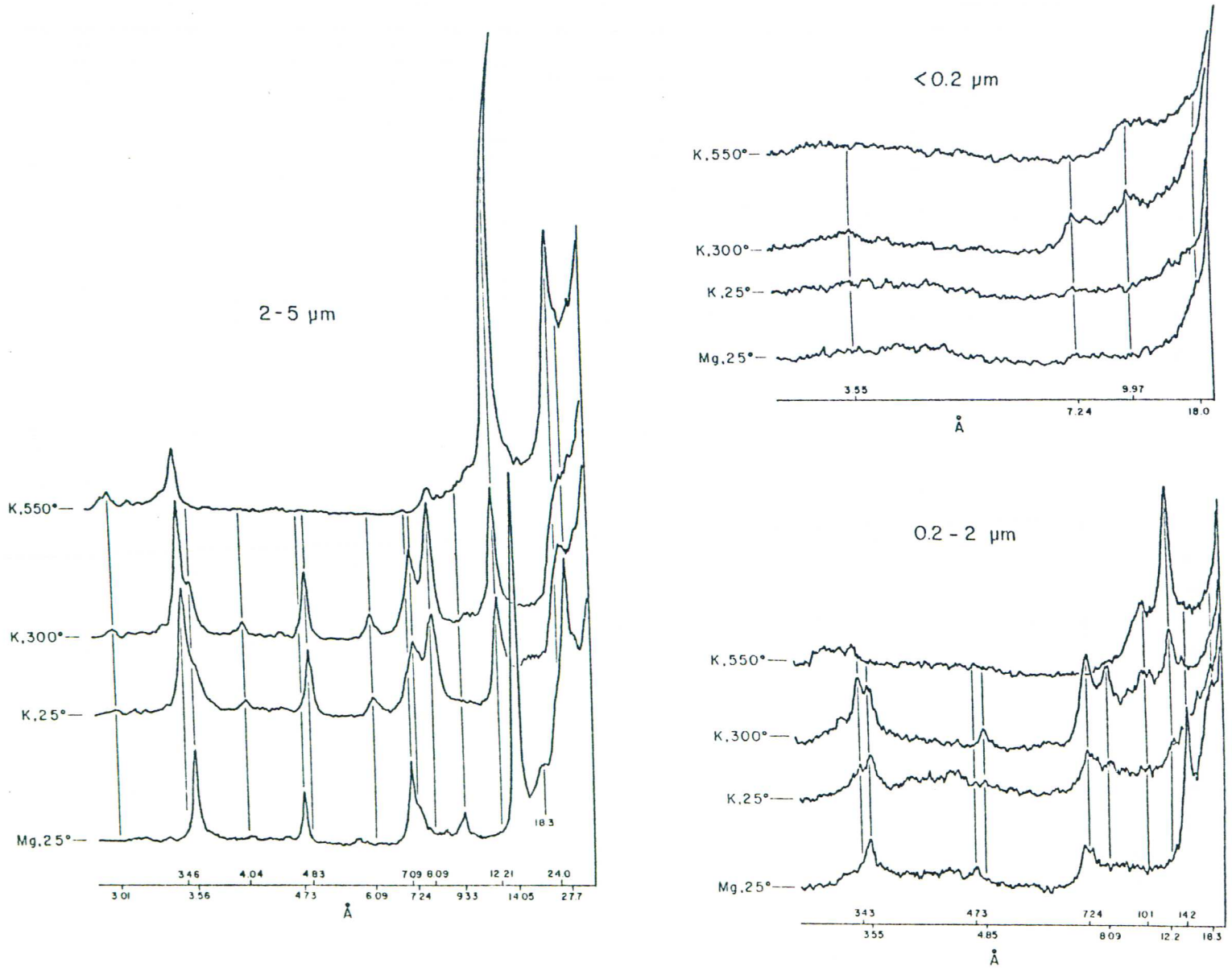



Figure 11. X-ray diffraction patterns for three fractions from the IICl horizon of profile 5 (Lab No. 6246).

X-ray diffraction patterns for the coarse clay of selected horizons from profile 6 are presented in Figure 12. As previously indicated by elemental distribution of the silt fractions in profile 6, the occurrence of feldspar, quartz, and mica in the upper meter of soil, while absent from the remainder of the profile, strongly suggests that these minerals have been added to the surface and incorporated into the upper meter of material. The small amount of chlorite present in the upper meter of soil is mostly interstratified with vermiculite and smectite. This chlorite in the soil may either have come from additions to the soil or, more likely, from 2:1 expansible minerals which formed hydroxy interlayers. Fanning and Jackson (1965) have also reported the increase in pedogenic chlorite with proximity to the soil surface in loess-derived soils in Wisconsin. Some discrete vermiculite was present in the coarse clay and fine silt fractions of the upper meter of profile 6. This probably has formed by the alteration of mica which was added to the soil.

Smectite and kaolinite are the dominant minerals of profile 6, and both are found in the fine silt and coarse and fine clay. Smectite levels decrease in the upper meter of soil but kaolinite levels are maintained throughout the profile. Smectite has probably formed following the weathering of the amphibole present in the parent rock and the greater intensity of weathering near the soil surface has resulted in a reduction in smectite levels. Kaolinite has been shown to form by

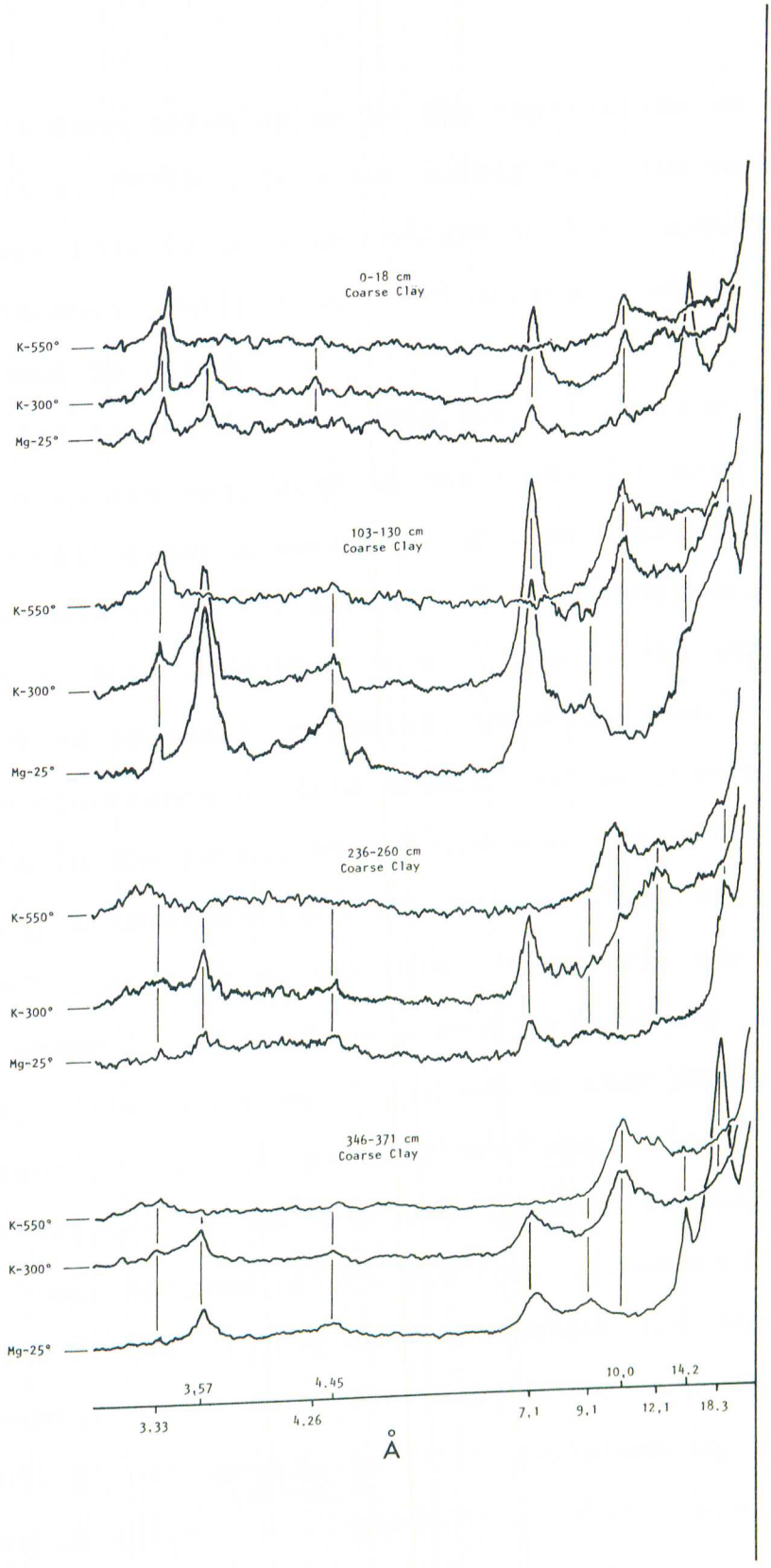



Figure 12. X-ray diffraction patterns of selected horizons from profile 6.

precipitation from solution or by the degradation of 2:1 minerals (Dixon, 1977). It seems likely that the smectite present in the soil is an intermediate in the formation of kaolinite although precipitation and crystallization from solution cannot be discounted.

Similar to profile 5, a regularly interstratified chlorite-vermiculite was found in the lower 2.5 meters of profile 6. The only other occurrences of a mineral of this nature have been related to the alteration of a trioctahedral chlorite (Johnson, 1964; Ross & Kodama, 1976). Due to the generally low crystallinity of pedogenic chlorite, the only viable explanation for the occurrence of this mineral is the presence of some chlorite in the parent rock which was altered to form this regularly interstratified chlorite-vermiculite. Due to the probable variability in the parent material, the chlorite need not be assumed to have been present throughout the parent rock, but may rather have been isolated to that material from which the lower portion of the profile formed. This would explain the occurrence of the regularly interstratified mineral only in the lower portion of the profile. Alternatively, the chlorite may have been distributed throughout the parent rock. The presence of the regularly interstratified mineral only in the lower half of the profile might be explained by this mineral being an early stage intermediate alteration product of chlorite which was further degraded in the upper portion of the profile.

## Relationship of Soil Mapping and Classification to Geology

The influence of parent material on the properties of soils has been recognized for many years. The earliest theories of soil formation were, in fact, based simply on the idea of soil as the result of rock weathering. One of the objectives of this study was to compare some of the soil mapping which has been done in Maryland during the last 20 years with the geologic mapping in this state.

Figure 13 shows two geologic units as mapped in Maryland (adapted from Weaver, 1968). One unit is serpentinite and other ultramafic rocks including dunite, peridotite, pyroxenite, and soapstone. The other unit is labeled undifferentiated mafic rocks which is a very general group including gabbro and metagabbro of varied composition, amphibolite, diabase, and some tonalite and pyroxenite. The origin and distribution of these rocks have been previously described in the review of the literature.

Those soil series in Maryland which have been described and mapped as having formed from serpentinite parent material are Aldino, Chrome, Conowingo, and Calvert. Of these, the first two are most prevalent. The soil survey reports of Montgomery, Howard, Baltimore, and Harford counties state that soils mapped in these series have formed from materials weathered from serpentinite. The Harford County report suggests that there may be loess overlying the serpentinite

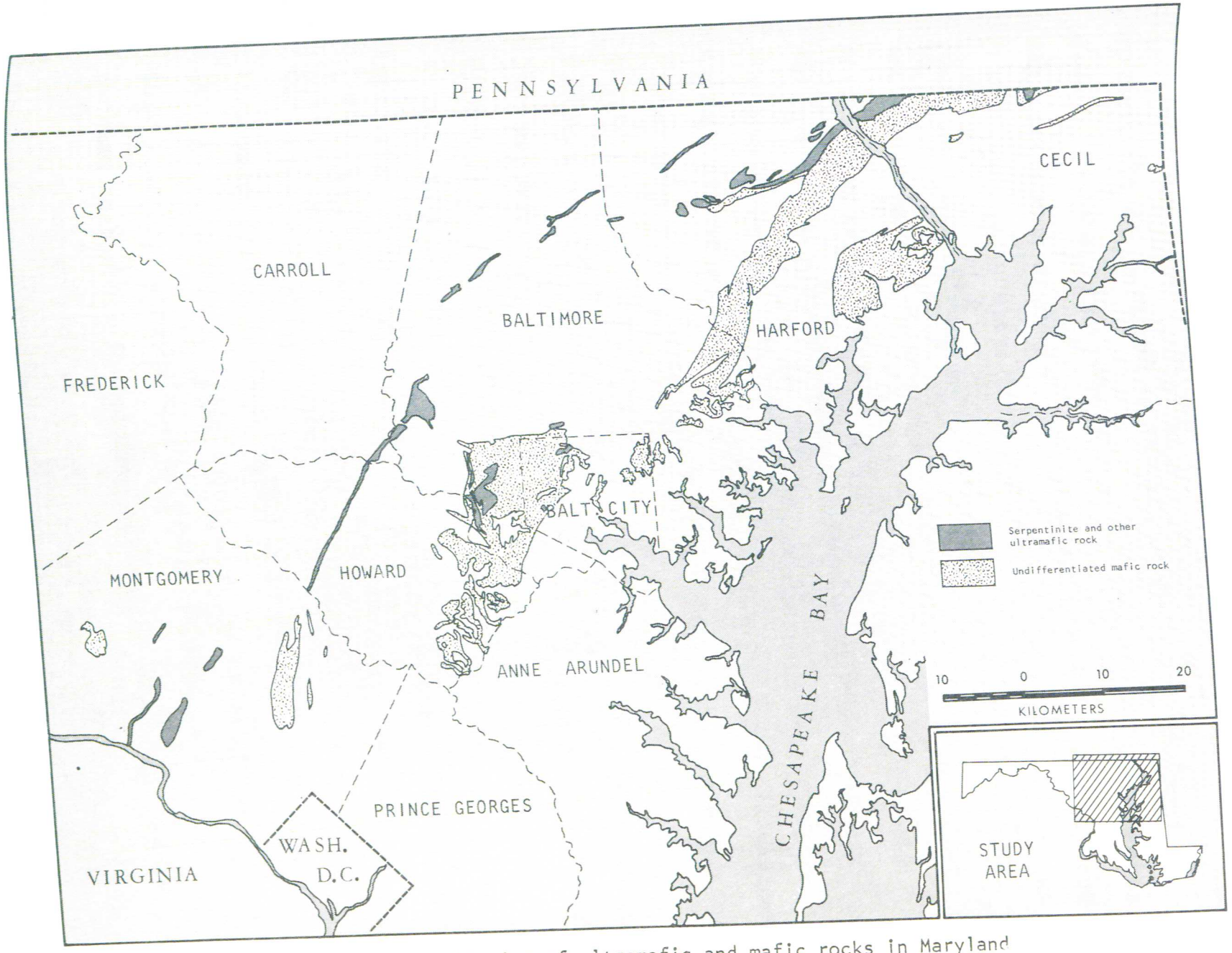



Figure 13. Distribution of ultramafic and mafic rocks in Maryland (adapted from Weaver, 1968).

residuum in soils mapped as Aldino. Only the Cecil County report indicates that some of the soils mapped in these series may have formed from non-serpentine mafic rocks such as gabbro.

Figure 14 shows the distribution of the Aldino, Chrome, Conowingo, and Calvert series, with respect to the ultramafic and mafic geology of Maryland. Data adapted from the county soil survey reports showing the areal extent of the various soil series on a county basis are presented in Table 9. In Montgomery County, the soil mapping correlates well with the geology of the area. Nearly all of the soils mapped as having formed from serpentinite do indeed coincide with the serpentinite geologic units; there is, however, one area of soils in the eastern part of Montgomery County which overlies tonalite rather than serpentinite. In Howard County, the small acreage of soils mapped as Aldino and Chrome also overlie non-serpentine mafic rocks. This suggests that profile morphology was used to the exclusion of geology information in mapping some of these soils.

The occurrence of these soils over non-serpentine parent materials is more extensive in Baltimore and Harford counties. It appears that while much of the soil mapped in the Aldino and Chrome series in these counties do not overlie serpentine, they are largely restricted to areas of mafic rock. This indicates that soils formed from ultramafic and mafic rocks may have similar morphology. There is, however, an area of these soils in the central part of Harford County which overlies Port Deposit Gneiss, a nonmafic rock. Nearly all of the soils

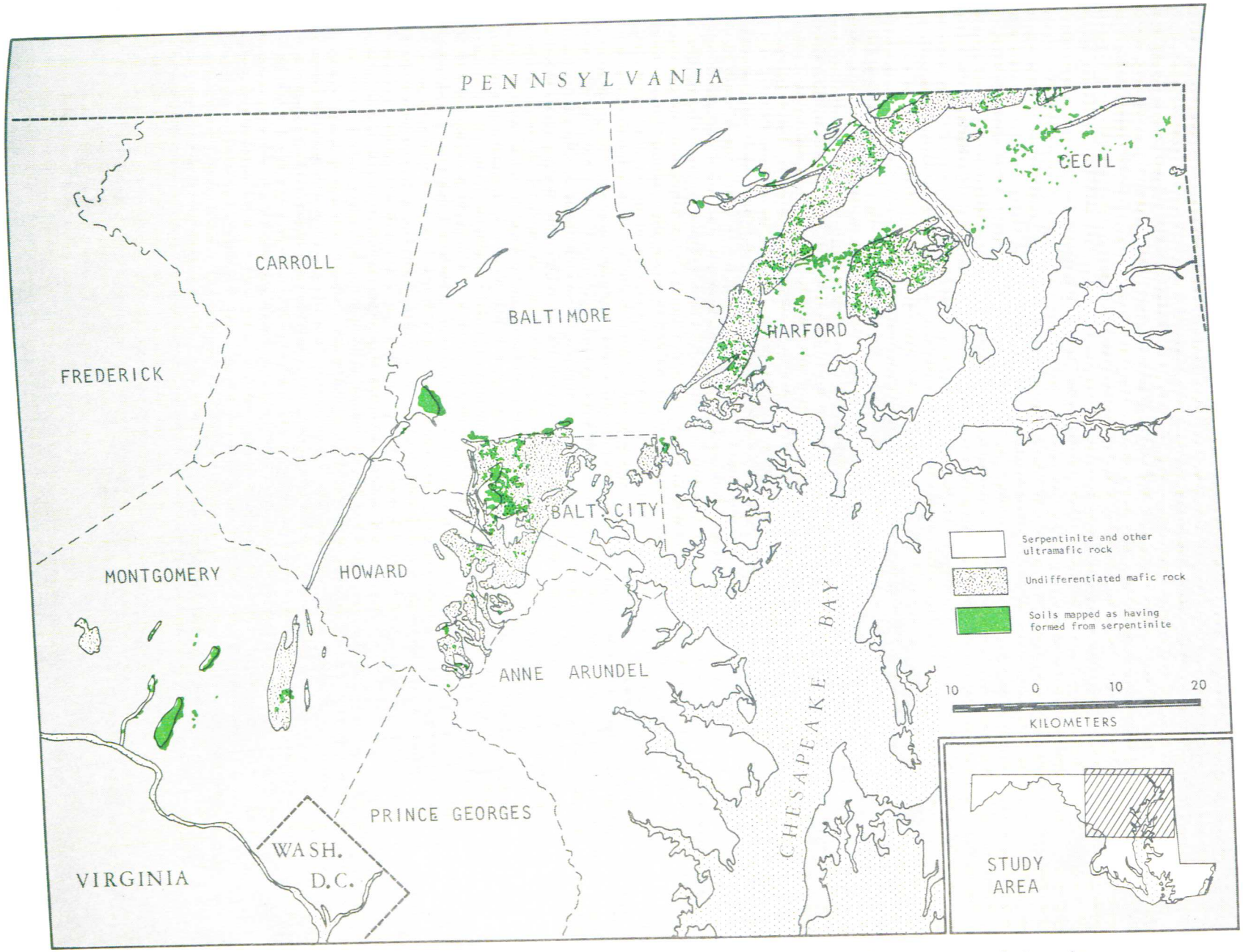



Figure 14. Distribution of soils mapped as having formed from serpentinite in relationship to ultramafic and mafic geology.

Table 9. Areal extent of soil series mapped as having formed from serpentinite.

| County | Aldino | Chrome | Conowingo | Calvert | County Total |
|---|---|---|---|---|---|
| | acres | | | | |
| Montgomery | 1,400 | 2,584 | 441 | 460 | 4,885 |
| Howard | 311 | 0 | 0 | 0 | 311 |
| Baltimore | 4,130 | 1,900 | 0 | 0 | 6,030 |
| Harford | 7,230 | 340 | 0 | 0 | 7,570 |
| Cecil | 2,265 | 2,041 | 171 | 0 | 4,477 |
| Series Total | 15,336 | 6,865 | 612 | 460 | 23,273 |

(Adapted from Andersen & Matthews, 1973; Matthews et al., 1960; Matthews & Hershberger, 1968; Reybold & Matthews, 1976; Smith & Matthews, 1975.)

under study in Harford County are mapped in the Aldino series, which is thought to have received loess additions. Although somewhat speculatory, it is conceivable that loess deposition in this part of the county could have partially masked the effects of the underlying residuum. This would, however, suggest that the soils were mapped on the basis of profile morphology, with a minimum consideration of available geologic information.

Soils mapped in the Aldino, Chrome, and Conowingo series in the northwestern and northern part of Cecil County overlie primarily serpentinite and also some mafic rocks. The most recently published geologic map of Cecil County, from which Figure 14 was designed, is of 1902 vintage. According to a more recent report, metavolcanic rocks including mafic types, underlie a much greater portion of Cecil County than once believed (Crowley et al., 1971). This may explain the distribution of the soils in the north central part of the county, which according to the 1902 map, overlie nonmafic materials. Since it stated in the soil survey report of Cecil County that these soils may have formed from non-serpentine mafic rocks as well as from serpentinite, the soil mapping may be consistent with the geology. Since soil mapping is much more detailed than most geologic mapping, it is potentially more accurate and may even be useful as an aid to geologic mapping, particularly if chemical and mineralogical analyses are employed.

The fact that the Cecil County report states that these series may be mapped over either serpentinite or non-serpentine

mafic rocks such as gabbro highlights an important problem. The previous discussion of physical, chemical, and mineralogical properties of serpentinite-derived soils and those formed from non-serpentine mafic rocks shows that there are significant differences which should affect use and management of these soils. It is obvious from Figure 14 that these important parent material differences have not been taken into account in soil mapping.

Table 10 shows the classification of the four soil series in Maryland which have supposedly formed from serpentinite. Also shown for comparison are the other Maryland soils which occur in the same subgroup as the serpentine soils, but have formed from other parent materials. Two thirds of these soils have formed from Ca-rich parent materials, and all of the parent materials are much different from serpentinite. It is noteworthy that both the Chrome series and Hagerstown series are classified in the same soil family. According to soil survey reports, the Hagerstown soil, which has formed from limestone, will produce 80 to 90 bushels of corn per acre under improved management, while the Chrome soil will produce only 25 bushels per acre. It is also interesting that the Aldino soils in Montgomery County, which have formed from serpentinite are estimated to produce 35 bushels of corn per acre under improved management, while the Aldino soils in Harford County, which have formed primarily from amphibolite and metagabbro with some eolian additions, are estimated to

*Table 10. Classification of Maryland serpentine soils and similarly classified soils and their parent materials.*

| Series | Classification | Other Maryland Series in this Subgroup | Family | Parent Material |
|---|---|---|---|---|
| Aldino | Typic Fragiudalf - Fine silty, mixed mesic | Readington | Fine loamy, mixed, mesic | shale and sandstone |
| | | Wiltshire | Fine loamy, mixed, mesic | local alluvium |
| Chrome | Typic Hapludalf - Fine, mixed, mesic | Hagerstown | Fine, mixed, mesic | limestone |
| | | Iredell | Fine, montmorillonitic, thermic | diabase |
| | | Relay | Fine loamy, mixed, mesic | metagabbro |
| | | Holinger | Fine loamy, mixed, mesic | micaceous limestone/ calciferous schist |
| | | Conestoga | Fine loamy, mixed, mesic | calciferous mica schists/ marble and limestone |
| | | Edom | Fine, illitic, mesic | impure limestone |
| Conowingo | Aquic Hapludalf - Fine loamy, mixed, mesic | Kelly | Fine, mixed, mesic | diabase/gabbro |
| Calvert | Typic Fragiaqualf - Fine silty, mixed, mesic | Loysville | Fine loamy, mixed, mesic | colluvium of cherty limestone |
| | | Robertsville | Fine silty, mixed, mesic | old alluvium (terrace) |
| | | Brinkerton | Fine silty, mixed, mesic | local alluvium from acid or calcareous shales |

(Adapted from Soil Survey Staff, 1977.)

produce 100 bushels per acre. Consideration of improvements in varieties and management practices between the times when the two reports were published still cannot account for such a large discrepancy. This further illustrates the need to differentiate between these soils.

As presently classified, the Aldino, Chrome, Conowingo and Calvert series are all described as having mixed mineralogy. Therefore, Harford County soils derived from mafic rock can correctly be classified in the Aldino series. Currently, there are no soil series recognized in Maryland in a serpentinitic mineralogy class. According to x-ray diffraction data, however, three of the four serpentinite-derived profiles in this study, had serpentine levels sufficiently high to be placed in a serpentinitic mineralogy class. Since Soil Taxonomy provides for the accommodation of these soils according to their distinctive mineralogy, the soil mapping in Maryland should reflect this in the recognition of soil series with serpentinitic mineralogy. This would allow for the separation of these morphologically similar soils which have formed from significantly different parent materials. The introduction of a serpentinitic soil family would hopefully also result in a better correlation in various counties and would encourage greater use of available geologic information in the mapping of these soils.

# CONCLUSIONS

## Genesis of Serpentine Soils

The weathering of serpentinite in Maryland, along with other processes of pedogenesis, have resulted in relatively shallow soils with dominantly silty textures. Figure 15 shows a generalized model of the genesis of a serpentinite-derived soil. The release and translocation of Fe has resulted in brownish colored B horizons. Impeded drainage may cause the Fe to become segregated as mottles or concretions. The processes of eluviation and illuviation of clay have produced argillic horizons which are weakly to moderately expressed. As a result of denudation, which counteracts the processes of profile development and horizon differentiation, soils which occur on greater slopes tend to have B horizons which are less strongly expressed. The Mg-rich parent material has resulted in the dominance of $Mg^{++}$ on the exchange complex. This has caused these soils to have fairly high pH values. The greater intensity of weathering near the surface has caused the general trend of increased $Mg^{++}$ saturation and increased pH with depth. Nickel and chromium levels are generally very high but they do show considerable variation from one location to another.

Both the elemental analyses of the silt fractions and mineralogical data have indicated that some material from a

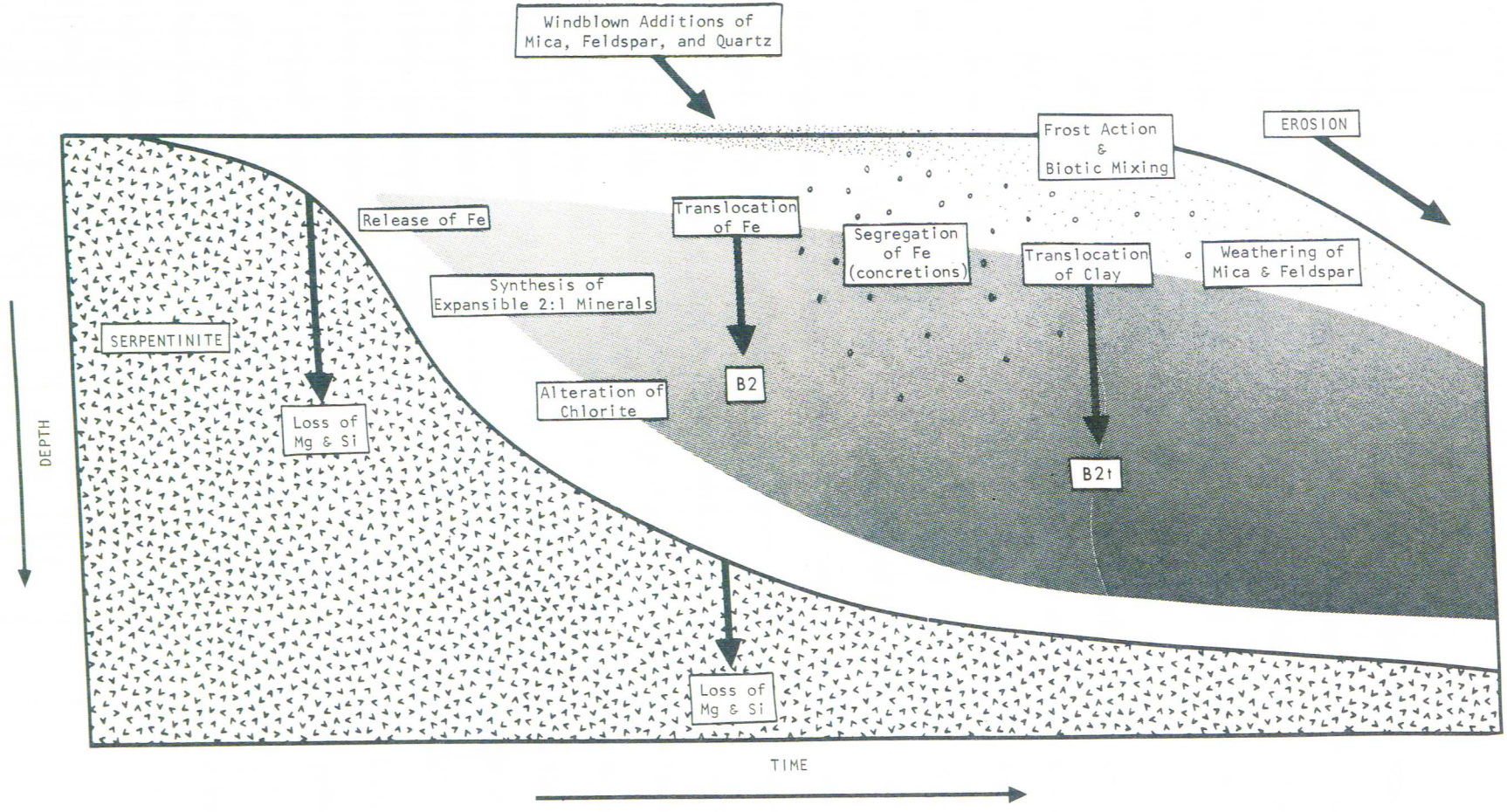



Figure 15. Generalized model of the genesis of serpentinite-derived soils in Maryland indicating major processes involved.

geologically different source has been added to the surface and incorporated into the serpentinite-derived soils in Montgomery, Baltimore, Harford, and Cecil counties. These additions have complicated the understanding of mineralogical transformations occurring in the soil.

Figure 16 shows the important transformations which occur during the genesis of serpentine soils. Serpentine minerals are generally abundant in the > 0.2 μm fractions of the soil, but are entirely absent from the fine clay ( < 0.2 μm) fraction. While some of the weathering products of serpentine are removed from the soil system by percolating water, others participate in the synthesis of smectite, which is most prominent in the finer fractions. Some hydroxy-interlayers may develop in the smectites forming pedogenic chlorite. The Fe which is released from serpentine structures or from Fe-rich accessory minerals remains in oxide form. Vermiculite is also generally abundant in these soils. While most of the vermiculite has probably formed by the alteration of chlorite associated with serpentine in the parent rock or by the alteration of mica which has been added to these sites, some vermiculite in the fine clay fraction may have been synthesized from the weathering products of serpentine. The dashed arrows in Figure 16 indicate the possible formation of Fe oxides as weathering of these minerals continues.

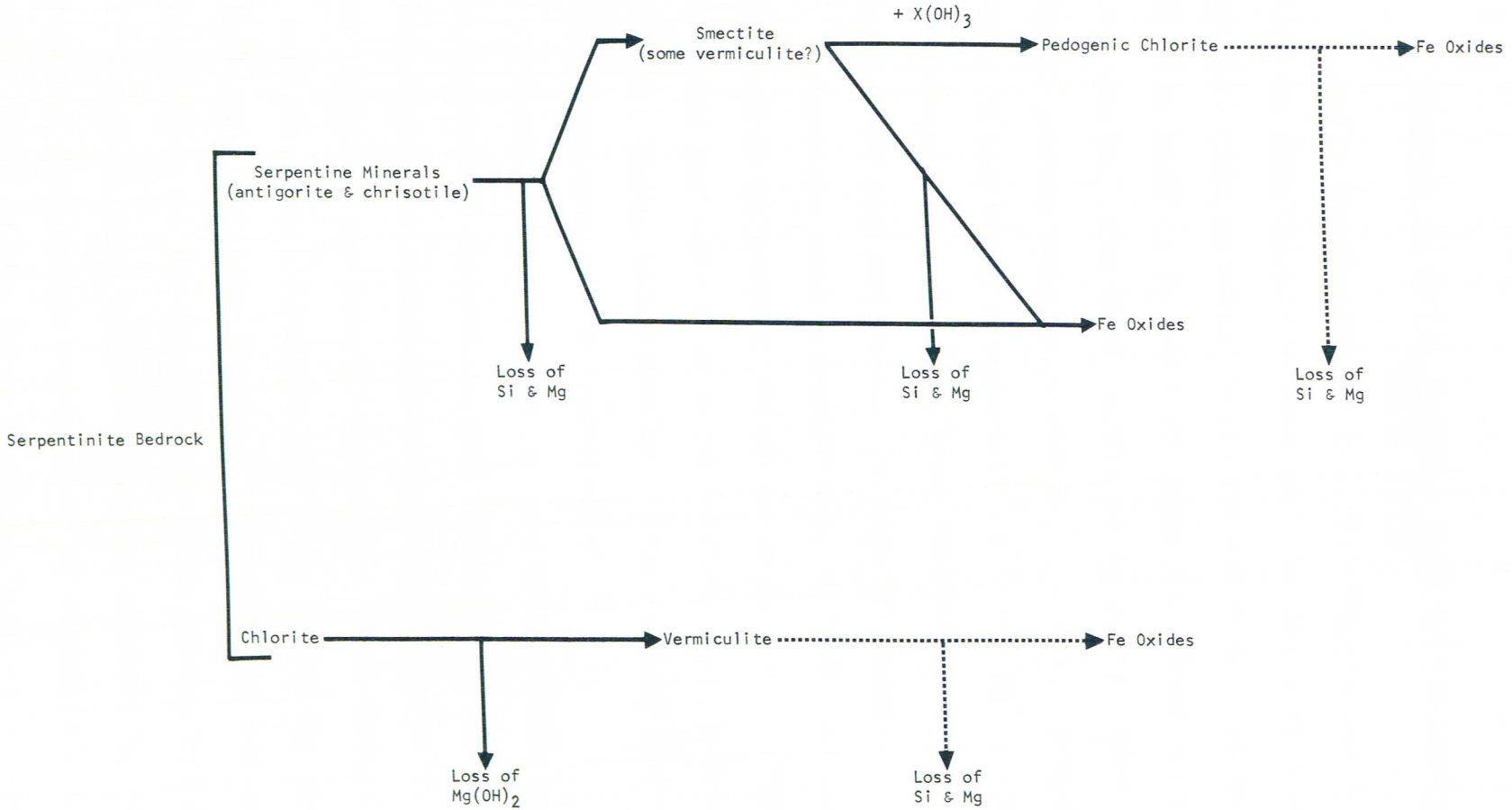



Figure 16. Mineral transformations involved in the genesis of serpentinite-derived soils.

## Genesis of Soils Derived from Non-Serpentine Mafic Rocks

Soils which have formed from non-serpentine mafic rock tend to be more deeply weathered than soils derived from serpentinite. The argillic horizons which are present in these soils also tend to be more strongly expressed than in many serpentine soils. The high levels of Ca and Mg which occur in the mafic parent materials result in a large proportion of the exchange sites being occupied by $Ca^{++}$ and $Mg^{++}$. Depending on the mineralogy, the high base saturation which generally ensues may or may not result in high pH values.

Particle size distribution, as well as elemental and mineralogical data shows evidence of eolian additions to these sites which may vary from a few centimeters up to one meter in thickness. These additions have also blurred the understanding of the mineralogy in these soils.

Minerals which occur in the mafic rocks such as plagioclase, pyroxene, amphibole, and chlorite are quickly and easily weathered and are virtually absent from the soils. Vermiculite and/or smectite are usually abundant. When occurring near the soil surface, these minerals may have formed by the alteration on windblown additions of mica. Vermiculite and smectite occurring deeper in the profile are most likely synthesis products. The kaolinite which is usually present in these soils is probably the weathering product of either plagioclase or smectite. Two of the three profiles studied showed the presence of a regularly interstratified chlorite-vermiculite in the fine

silt and coarse clay fractions, which has probably formed by the alteration of chlorite which was present in the parent rock.

## Soil Mapping and Geology

In all five counties which contain soils mapped in those series described as having formed from serpentinite, some of these soils are mapped over rocks other than serpentinite. This is most striking in Harford County. While some of these soils are mapped over acidic rocks, they are largely restricted to areas of mafic rocks.

The characterization of soils formed from serpentinite and from non-serpentine mafic rocks shows that there are important practical differences between these soils such as depth to bedrock, degree of shrink swell hazard, and fertility. It is, therefore, important that distinctions between these soils be clearly made. In order for distinctions to be made in the classification and mapping of these soils, there should be the recognition of serpentinitic soil families in Maryland. Additionally, there needs to be a greater utilization of available geologic information in the mapping of these soils.

Appendix A. Mechanical analyses of the profiles studied.

| Depth cm. | Lab No. | Size class and particle diameter (mm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | | | Sand | | | | | Silt | |
| | | Sand 2-0.05 | Silt 0.05-0.002 | Clay <0.002 | Very Coarse 2-1 | Coarse 1-0.5 | Medium 0.5-0.25 | Fine 0.25-0.10 | Very Fine 0.10-0.05 | Coarse 0.05-0.02 | Fine 0.02-0.002 |
| Profile 1 | | | | | | | | | | | |
| 0-6 | 6202 | 18.0 | 66.1 | 15.9 | 8.7 | 4.5 | 1.3 | 1.7 | 1.8 | 19.9 | 46.2 |
| 6-21 | 6203 | 18.9 | 65.1 | 16.0 | 8.5 | 4.3 | 1.3 | 1.5 | 3.3 | 20.8 | 44.3 |
| 21-26 | 6204 | 20.0 | 65.4 | 14.6 | 10.0 | 4.3 | 1.4 | 2.0 | 2.3 | 18.6 | 46.8 |
| 26-32 | 6205 | 13.1 | 62.1 | 24.8 | 5.4 | 2.5 | 1.1 | 2.0 | 2.1 | 18.9 | 43.2 |
| 32-38 | 6206 | 10.1 | 58.1 | 31.8 | 4.2 | 2.2 | 0.9 | 1.5 | 1.3 | 17.7 | 40.4 |
| 38-60 (si) | 6207 | 13.4 | 68.8 | 17.8 | 8.2 | 2.0 | 0.7 | 1.1 | 1.4 | 30.2 | 38.6 |
| 38-60 (c) | 6208 | 17.7 | 45.9 | 36.4 | 10.4 | 2.6 | 0.9 | 0.6 | 3.2 | 14.1 | 31.8 |
| 38-60 (g) | 6209 | 45.3 | 38.9 | 15.8 | 32.9 | 7.4 | 2.0 | 2.5 | 0.5 | 14.9 | 24.0 |
| Profile 2 | | | | | | | | | | | |
| 0-11 | 6210 | 27.3 | 54.9 | 17.8 | 3.8 | 5.3 | 4.2 | 6.6 | 7.4 | 17.3 | 37.6 |
| 11-18 | 6211 | 23.9 | 55.3 | 20.8 | 3.4 | 5.2 | 3.7 | 4.7 | 6.9 | 19.3 | 36.0 |
| 18-29 | 6212 | 21.6 | 48.7 | 29.7 | 2.8 | 4.4 | 3.6 | 6.3 | 4.5 | 15.2 | 33.5 |
| 29-45 | 6213 | 24.1 | 34.5 | 41.4 | 1.3 | 5.1 | 4.1 | 7.3 | 6.3 | 8.4 | 26.1 |
| 45-54 | 6214 | 37.7 | 31.7 | 30.6 | 3.3 | 10.3 | 6.2 | 7.5 | 10.4 | 8.0 | 23.7 |
| 54-75 | 6215 | 43.1 | 35.6 | 21.3 | 4.2 | 9.8 | 6.7 | 12.9 | 9.5 | 11.4 | 24.2 |
| 75-92 | 6216 | 86.0 | 7.7 | 6.3 | 38.8 | 24.6 | 8.9 | 10.0 | 3.7 | 3.7 | 4.0 |
| 92-110 | 6217 | 91.6 | 6.4 | 2.0 | 45.9 | 25.0 | 9.0 | 9.7 | 2.0 | 3.9 | 2.5 |
| 110-138 | 6218 | 65.4 | 14.9 | 19.7 | 26.5 | 17.6 | 7.5 | 10.8 | 3.0 | 5.0 | 9.9 |
| 138-154 | 6219 | 75.8 | 12.0 | 12.2 | 28.6 | 20.5 | 8.8 | 12.9 | 5.0 | 4.6 | 7.4 |

Appendix A (continued)

| Depth cm. | Lab No. | Size class and particle diameter (mm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | | | Sand | | | | | Silt | |
| | | Sand 2-0.05 | Silt 0.05-0.002 | Clay <0.002 | Very Coarse 2-1 | Coarse 1-0.5 | Medium 0.5-0.25 | Fine 0.25-0.10 | Very Fine 0.10-0.05 | Coarse 0.05-0.02 | Fine 0.02-0.002 |
| Profile 3 | | | | | | | | | | | |
| 0-4 | 6220 | 8.5 | 78.3 | 13.2 | 4.1 | 2.0 | 1.1 | 0.7 | 0.6 | 19.3 | 59.0 |
| 4-16 | 6221 | 12.6 | 72.6 | 14.8 | 5.7 | 3.3 | 1.4 | 1.3 | 0.9 | 17.9 | 54.7 |
| 16-28 | 6222 | 14.1 | 66.4 | 19.5 | 6.3 | 3.3 | 1.4 | 1.9 | 1.2 | 15.7 | 50.7 |
| 28-40 | 6223 | 9.4 | 57.8 | 32.8 | 3.7 | 1.8 | 1.0 | 0.7 | 2.2 | 13.9 | 43.9 |
| 40-53 | 6224 | 18.1 | 52.1 | 29.8 | 7.4 | 4.3 | 1.8 | 2.3 | 2.3 | 12.1 | 40.0 |
| 53-75 | 6225 | 21.9 | 46.8 | 31.3 | 7.1 | 4.4 | 2.6 | 3.9 | 3.9 | 8.1 | 38.7 |
| 75-91 | 6226 | 26.3 | 47.0 | 26.7 | 6.6 | 4.7 | 2.9 | 5.5 | 6.6 | 12.5 | 34.5 |
| 91-107 | 6227 | 35.6 | 40.1 | 24.3 | 14.3 | 6.3 | 3.5 | 5.4 | 6.1 | 10.5 | 29.6 |
| 107-123 | 6228 | 38.0 | 40.5 | 21.5 | 11.4 | 6.6 | 4.4 | 7.7 | 7.9 | 12.2 | 28.3 |
| 123-139 | 6229 | 34.2 | 51.8 | 14.0 | 10.2 | 5.8 | 4.2 | 6.7 | 7.3 | 14.3 | 37.5 |
| 139-155 | 6230 | 33.0 | 54.3 | 12.7 | 10.1 | 5.8 | 3.3 | 5.6 | 8.2 | 23.4 | 30.9 |
| 155-170 | 6231 | 35.1 | 50.2 | 14.7 | 11.3 | 6.5 | 3.5 | 6.3 | 7.5 | 15.9 | 34.3 |
| Profile 4 | | | | | | | | | | | |
| 0-2 | 6232 | 10.3 | 66.5 | 23.2 | 1.9 | 1.3 | 1.7 | 0.7 | 4.7 | 11.4 | 55.1 |
| 2-8 | 6233 | 8.9 | 71.0 | 20.1 | 1.0 | 2.1 | 1.7 | 1.9 | 2.2 | 26.8 | 44.2 |
| 2-18 | 6234 | 12.7 | 67.2 | 20.1 | 2.5 | 3.5 | 2.1 | 2.2 | 2.4 | 24.6 | 42.6 |
| 18-26 | 6235 | 25.1 | 60.5 | 14.4 | 9.5 | 6.3 | 2.9 | 3.4 | 3.0 | 17.6 | 42.9 |
| 26-43 | 6236 | 19.8 | 60.0 | 20.2 | 5.9 | 4.0 | 2.3 | 3.7 | 3.9 | 19.9 | 40.1 |
| 41-43 | 6237 | 21.9 | 57.9 | 20.2 | 8.1 | 4.0 | 2.2 | 2.0 | 5.6 | 19.2 | 38.7 |
| Profile 5 | | | | | | | | | | | |
| 0-6 | 6238 | 13.9 | 71.7 | 14.4 | 2.3 | 2.3 | 0.9 | 3.4 | 5.0 | 27.5 | 44.2 |
| 6-16 | 6239 | 17.8 | 68.6 | 13.6 | 6.0 | 2.9 | 1.2 | 3.5 | 4.2 | 19.5 | 49.1 |

Appendix A (continued)

| Depth cm. | Lab No. | Size class and particle diameter (mm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | | | Sand | | | | Silt | | |
| | | Sand 2-0.05 | Silt 0.05-0.002 | Clay <0.002 | Very Coarse 2-1 | Coarse 1-0.5 | Medium 0.5-0.25 | Fine 0.25-0.10 | Very Fine 0.10-0.05 | Coarse 0.05-0.02 | Fine 0.02-0.002 |
| Profile 5 (continued) | | | | | | | | | | | |
| 16-32 | 6240 | 8.4 | 70.6 | 21.0 | 1.0 | 1.2 | 0.7 | 2.5 | 3.0 | 18.6 | 52.0 |
| 32-55 | 6241 | 3.8 | 68.8 | 27.4 | 0.0 | 0.1 | 0.1 | 1.2 | 2.4 | 19.7 | 49.1 |
| 55-75 | 6242 | 3.5 | 74.1 | 22.4 | 0.0 | 0.3 | 0.3 | 0.9 | 2.0 | 25.2 | 48.9 |
| 75-95 | 6243 | 8.9 | 70.7 | 20.4 | 0.9 | 1.1 | 0.7 | 2.5 | 3.7 | 26.8 | 43.9 |
| 95-110 | 6244 | 51.9 | 37.0 | 11.1 | 4.6 | 14.2 | 5.4 | 14.3 | 13.4 | 15.5 | 21.5 |
| 110-130 | 6245 | 58.9 | 33.0 | 8.1 | 7.5 | 19.6 | 4.9 | 15.0 | 11.9 | 13.4 | 19.6 |
| 130-155 | 6246 | 51.2 | 37.4 | 11.4 | 4.4 | 17.0 | 4.4 | 12.6 | 12.8 | 14.1 | 23.3 |
| 155-175 | 6247 | 66.9 | 30.2 | 2.9 | 11.0 | 20.3 | 8.8 | 14.3 | 12.5 | 14.4 | 15.8 |
| 175-205 | 6248 | 65.8 | 30.9 | 3.3 | 12.6 | 19.8 | 8.1 | 12.7 | 12.6 | 15.9 | 15.0 |
| Profile 6 | | | | | | | | | | | |
| 0-18 | 6249 | 11.4 | 71.1 | 17.5 | 1.7 | 1.6 | 1.2 | 3.3 | 3.6 | 25.9 | 45.2 |
| 18-55 | 6250 | 7.1 | 44.9 | 48.0 | 1.7 | 0.8 | 0.3 | 1.6 | 2.7 | 10.0 | 34.9 |
| 55-78 | 6251 | 11.2 | 33.1 | 55.7 | 1.5 | 1.4 | 0.7 | 3.1 | 4.5 | 7.1 | 26.0 |
| 78-103 | 6252 | 20.5 | 30.5 | 49.0 | 1.6 | 3.1 | 1.4 | 7.0 | 7.4 | 8.0 | 22.5 |
| 103-130 | 6253 | 39.0 | 33.1 | 27.9 | 3.1 | 5.2 | 3.7 | 11.9 | 15.1 | 11.4 | 21.7 |
| 130-158 | 6254 | 38.8 | 31.4 | 29.8 | 0.3 | 3.6 | 4.1 | 15.2 | 15.6 | 10.4 | 21.0 |
| 158-183 | 6255 | 25.2 | 49.2 | 25.6 | 0.4 | 1.0 | 1.0 | 8.3 | 14.5 | 17.6 | 31.6 |
| 183-211 | 6256 | 43.4 | 43.5 | 13.1 | 1.4 | 3.1 | 3.2 | 13.4 | 22.3 | 19.3 | 24.2 |
| 211-236 | 6257 | 50.4 | 38.0 | 11.6 | 2.1 | 6.1 | 4.8 | 16.0 | 21.4 | 18.5 | 19.5 |
| 236-260 | 6258 | 57.8 | 34.3 | 7.9 | 4.0 | 9.4 | 6.7 | 17.1 | 20.6 | 15.6 | 18.7 |
| 260-285 | 6259 | 64.9 | 25.1 | 10.0 | 1.5 | 10.1 | 9.0 | 23.2 | 21.1 | 11.7 | 13.4 |
| 285-310 | 6260 | 70.7 | 20.8 | 8.5 | 2.1 | 10.7 | 9.0 | 26.2 | 22.7 | 8.4 | 12.4 |

Appendix A (continued)

| Depth cm. | Lab No. | Size class and particle diameter (mm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | | | Sand | | | | Silt | | |
| | | Sand 2-0.05 | Silt 0.05-0.002 | Clay <0.002 | Very Coarse 2-1 | Coarse 1-0.5 | Medium 0.5-0.25 | Fine 0.25-0.10 | Very Fine 0.10-0.05 | Coarse 0.05-0.02 | Fine 0.02-0.002 |
| Profile 6 (continued) | | | | | | | | | | | |
| 310-346 | 6261 | 63.7 | 32.0 | 4.3 | 1.8 | 8.6 | 6.3 | 22.6 | 24.4 | 13.6 | 18.4 |
| 346-371 | 6262 | 65.3 | 28.0 | 6.7 | 6.6 | 12.5 | 7.4 | 19.8 | 19.0 | 12.6 | 15.4 |
| 371-383 | 6263 | 66.3 | 27.2 | 6.5 | 10.0 | 12.5 | 7.5 | 18.0 | 18.3 | 10.5 | 16.7 |
| 383-400 | 6264 | 68.0 | 26.5 | 5.5 | 8.3 | 13.5 | 7.4 | 20.4 | 18.4 | 10.0 | 16.5 |
| 400-430 | 6265 | 69.9 | 26.7 | 3.4 | 8.1 | 10.4 | 7.9 | 23.7 | 19.8 | 11.5 | 15.2 |
| Profile 7 | | | | | | | | | | | |
| 0-3 | 6266 | 10.6 | 71.5 | 17.9 | 1.3 | 3.4 | 1.3 | 2.2 | 2.4 | 21.8 | 49.7 |
| 3-27 | 6267 | 15.5 | 66.6 | 17.9 | 5.8 | 3.8 | 1.6 | 2.1 | 2.2 | 18.6 | 48.0 |
| 27-43 | 6268 | 15.5 | 62.6 | 21.9 | 5.1 | 3.7 | 1.5 | 2.6 | 2.6 | 18.6 | 44.0 |
| 43-70 | 6269 | 13.9 | 63.7 | 22.4 | 4.2 | 3.0 | 1.4 | 2.5 | 2.8 | 18.4 | 45.3 |
| 70-92 | 6270 | 12.6 | 65.8 | 21.6 | 3.7 | 2.8 | 1.2 | 2.2 | 2.7 | 20.3 | 45.5 |
| 92-100 | 6271 | 26.3 | 47.8 | 25.9 | 6.2 | 6.5 | 2.9 | 5.3 | 5.4 | 14.5 | 33.3 |
| 100-104 | 6272 | 40.7 | 36.1 | 23.2 | 11.1 | 7.8 | 4.1 | 9.8 | 7.9 | 12.7 | 23.4 |

Appendix B. Extractable nutrient levels, pH, and Ca:Mg ratios for samples from reconnaissance sites.

| Lab. No. | Site No. | Depth cm. | pH | Mg | P | K | Ca | Ca:Mg |
|---|---|---|---|---|---|---|---|---|
| | | | | ppm | | | | |
| 6001 | 1 | 0-5 | 4.8 | 265 | 3 | 69 | 297 | 1.16 |
| 6002 | | 5-15 | 4.5 | 75 | 2 | 27 | 13 | .14 |
| 6003 | | 15-25 | 4.9 | 248 | 1 | 19 | 63 | .32 |
| 6004 | | 25-38 | 5.4 | 373 | 2 | 14 | 213 | .55 |
| 6005 | | 38-63 | 6.0 | 443 | 3 | 21 | 400 | .89 |
| 6006 | 2 | 50-60 | 6.4 | 795 | 4 | 25 | 13 | .02 |
| 6007 | 4 | 45-55 | 5.2 | 550 | 2 | 20 | 13 | .02 |
| 6008 | | 55-65 | 5.6 | 488 | 3 | 14 | 13 | .02 |
| 6009 | 5 | 50-75 | 6.2 | 500 | 3 | 24 | 13 | .02 |
| 6010 | | 75+ | 6.2 | 645 | 2 | 19 | 20 | .02 |
| 6011 | 6 | 40 | 6.0 | 545 | 4 | 21 | 770 | 1.47 |
| 6012 | | 70 | 6.3 | 338 | 42 | 6 | 503 | 1.53 |
| 6013 | 7 | 46 | 6.1 | 673 | 5 | 25 | 773 | 1.19 |
| 6014 | | 84-88 | 6.7 | 588 | 24 | 13 | 790 | 1.44 |
| 6015 | 8 | 55-65 | 6.5 | 585 | 4 | 13 | 113 | .19 |
| 6016 | | 65-75 | 6.3 | 540 | 4 | 13 | 90 | .15 |
| 6017 | 9 | | 5.8 | 703 | 3 | 17 | 603 | .91 |
| 6018 | 10 | 0-6 | 5.7 | 708 | 2 | 52 | 1073 | 1.52 |
| 6019 | | 10-25 | 6.5 | 678 | 3 | 30 | 740 | 1.13 |
| 6020 | 11A | | 5.4 | 628 | 2 | 16 | 10 | .02 |
| 6021 | | | 4.8 | 125 | 2 | 24 | 10 | .08 |
| 6022 | | | 5.1 | 183 | 2 | 22 | 10 | .06 |
| 6023 | | | 4.8 | 253 | 4 | 101 | 155 | .74 |
| 6024 | 11B | | 6.5 | 188 | 1 | 21 | 530 | 2.94 |
| 6025 | | | 6.4 | 183 | 1 | 14 | 410 | 2.50 |
| 6026 | | | 7.0 | 248 | 3 | 42 | 1410 | 6.18 |
| 6027 | 12A | 2-0 | | | | | | |
| 6028 | | 0-3 | | 678 | 2 | 91 | 220 | .33 |
| 6029 | | 3-12 | 6.0 | 730 | 1 | 26 | 135 | .19 |

Appendix B (continued)

| Lab. No. | Site No. | Depth cm. | pH | Mg | P | K | Ca | Ca:Mg |
|---|---|---|---|---|---|---|---|---|
| | | | | ppm | | | | |
| 6030 | | 12-20 | 6.7 | 768 | 2 | 17 | 45 | .05 |
| 6031 | | 20-34 | 6.6 | 815 | 2 | 17 | 20 | .02 |
| 6032 | | 34-44 | 6.7 | 858 | 2 | 18 | 15 | .02 |
| 6033 | | 44-52 | 6.8 | 840 | 2 | 19 | 15 | .02 |
| 6034 | | 52-58 | 7.1 | 840 | 2 | 19 | 15 | .02 |
| 6035 | | 58-65 | 7.1 | 795 | 2 | 19 | 10 | .02 |
| 6036 | | 65-70 | 7.2 | 725 | 3 | 17 | 10 | .02 |
| 6037 | 12B | 0-10 | 6.5 | 813 | 2 | 37 | 320 | .41 |
| 6038 | 12C | 0-15 | 6.6 | 828 | 2 | 44 | 375 | .48 |
| 6039 | 13 | 0-15 | 4.8 | 655 | 2 | 32 | 100 | .24 |
| 6040 | | 15-25 | 4.6 | 195 | 1 | 17 | 17 | .05 |
| 6041 | | 25-35 | 4.7 | 195 | 2 | 11 | 23 | .08 |
| 6042 | | 35-45 | 5.1 | 340 | 2 | 15 | 193 | .42 |
| 6043 | | 45-55 | 5.4 | 475 | 3 | 19 | 340 | .64 |
| 6044 | | 55-65 | 5.6 | 528 | 2 | 20 | 440 | .84 |
| 6045 | | 65-75 | 5.8 | 688 | 3 | 19 | 550 | .78 |
| 6046 | | 75-85 | 5.8 | 62.8 | 1 | 14 | 660 | 1.16 |
| 6047 | | 85-90 | 5.8 | 658 | 2 | 13 | 537 | .81 |
| 6048 | 14 | 25-35 | 5.2 | 625 | 1 | 14 | 13 | .02 |
| 6049 | | 35-40 | 5.2 | 383 | 1 | 18 | 27 | .04 |
| 6050 | 15A | 30-35 | 6.3 | 208 | 2 | 13 | 450 | 2.18 |
| 6051 | | 40-50 | 6.4 | 330 | 3 | 15 | 507 | 1.55 |
| 6052 | 15B | 0-15 | 6.3 | 363 | 4 | 17 | 843 | 2.29 |
| 6053 | | 15-35 | 5.9 | 548 | 5 | 20 | 447 | 0.84 |
| 6054 | | 35-45 | 6.0 | 560 | 4 | 17 | 367 | 0.70 |
| 6055 | 16 | 35-45 | 5.6 | 448 | 3 | 17 | 930 | 2.11 |
| 6056 | | 45-55 | 5.8 | 465 | 3 | 10 | 887 | 1.94 |
| 6057 | | 55-65 | 5.6 | 490 | 3 | 22 | 830 | 1.76 |
| 6058 | 17 | 30-40 | 5.8 | 428 | 2 | 19 | 650 | 1.54 |
| 6059 | | 40-50 | 6.5 | 440 | 3 | 19 | 470 | 1.08 |
| 6060 | | 50-60 | 6.6 | 433 | 2 | 12 | 500 | 1.21 |

Appendix B (continued)

| Lab. No. | Site No. | Depth cm. | pH | Mg | P | K | Ca | Ca:Mg |
|---|---|---|---|---|---|---|---|---|
| | | | | ppm | | | | |
| 6061 | | 60-70 | 6.6 | 530 | 3 | 13 | 620 | 1.22 |
| 6062 | | 70-80 | 6.8 | 560 | 2 | 14 | 705 | 1.34 |
| 6063 | | 80-90 | 7.1 | 418 | 2 | 12 | 720 | 1.78 |
| 6064 | | 90-100 | 7.1 | 423 | 2 | 12 | 720 | 1.74 |
| 6065 | 18 | 100-110 | 6.5 | 473 | 2 | 19 | 285 | 0.60 |
| 6066 | | 110-120 | 6.4 | 470 | 2 | 21 | 280 | 0.60 |
| 6067 | | 120-130 | 6.4 | 650 | 3 | 19 | 310 | 0.49 |
| 6068 | | 130-140 | 6.5 | 770 | 2 | 16 | 355 | 0.50 |
| 6069 | 19 | 80-90 | 5.5 | 430 | 2 | 19 | 70 | 0.16 |
| 6070 | | 90-100 | 5.5 | 410 | 2 | 15 | 150 | 0.18 |
| 6071 | | 110-115 | 5.5 | 513 | 2 | 21 | 95 | 0.18 |
| 6072 | | 115-125 | 5.9 | 550 | 2 | 12 | 120 | 0.22 |
| 6073 | 20 | 145-155 | 6.8 | 805 | 24 | 34 | 135 | 0.16 |
| 6074 | | 155-165 | 7.0 | 525 | 16 | 37 | 120 | 0.22 |
| 6075 | 21A | 0-10 | 4.9 | 360 | 3 | 38 | 10 | 0.03 |
| 6076 | | 30-40 | 4.6 | 58 | 2 | 14 | 10 | 0.19 |
| 6077 | | 70-80 | 5.1 | 138 | 2 | 17 | 10 | 0.08 |
| 6078 | 21B | 0-10 | 4.9 | 40 | 2 | 34 | 10 | 0.41 |
| 6079 | | 45-55 | 5.1 | 108 | 1 | 16 | 10 | 0.11 |
| 6080 | | 75-85 | 5.4 | 120 | 1 | 18 | 10 | 0.09 |
| 6081 | 22 | 0-10 | 6.5 | 233 | 13 | 78 | 1050 | 4.93 |
| 6082 | | 25-30 | 5.7 | 183 | 2 | 27 | 575 | 3.15 |
| 6083 | | 40-50 | 5.6 | 183 | 2 | 23 | 535 | 2.95 |
| 6084 | | 90-95 | 5.3 | 288 | 2 | 18 | 575 | 2.00 |
| 6085 | | 110-120 | 5.4 | 265 | 2 | 12 | 510 | 1.94 |
| 6086 | | 160-165 | 5.3 | 338 | 2 | 13 | 505 | 1.50 |
| 6087 | 23 | 0-10 | 6.2 | 303 | 15 | 26 | 1120 | 3.71 |
| 6088 | | 20-25 | 5.5 | 260 | 2 | 15 | 935 | 3.63 |
| 6089 | | 30-35 | 5.5 | 305 | 2 | 12 | 685 | 2.29 |
| 6090 | | 45-55 | 5.8 | 608 | 2 | 16 | 615 | 1.32 |
| 6091 | | 70-75 | 5.8 | 510 | 3 | 24 | 660 | 1.31 |

Appendix B (continued)

| Lab. No. | Site No. | Depth cm. | pH | Mg | P | K | Ca | Ca:Mg |
|---|---|---|---|---|---|---|---|---|
| | | | | ppm | | | | |
| 6092 | | 80-85 | 5.7 | 563 | 3 | 23 | 685 | 1.34 |
| 6093 | 24 | 0-10 | 5.5 | 273 | 5 | 47 | 630 | 2.39 |
| 6094 | | 30-40 | 4.6 | 238 | 2 | 22 | 255 | 1.07 |
| 6095 | | 75-80 | 5.0 | 253 | 2 | 14 | 255 | 1.01 |
| 6096 | | 90-100 | 5.5 | 265 | 2 | 13 | 340 | 1.29 |
| 6097 | 25A | 105-115 | 4.5 | 248 | 1 | 21 | 405 | 1.64 |
| 6098 | | 160-175 | 4.7 | 258 | 2 | 36 | 650 | 2.52 |
| 6099 | 25B | 110-120 | 4.7 | 295 | 1 | 5 | 60 | .20 |
| 6100 | | 140-150 | 4.8 | 113 | 1 | 7 | 20 | .17 |
| 6101 | | 165-170 | 4.6 | 270 | 2 | 50 | 445 | 1.65 |
| 6102 | 26 | 0-10 | 5.6 | 388 | 2 | 45 | 1595 | 4.21 |
| 6103 | | 25-40 | 5.2 | 305 | 1 | 53 | 145 | .48 |
| 6104 | | 50-60 | 5.3 | 400 | 2 | 59 | 245 | .69 |
| 6105 | | 70-80 | 5.5 | 508 | 2 | 21 | 420 | .93 |
| 6106 | 27 | 0-10 | 4.5 | 245 | 2 | 19 | 10 | .05 |
| 6107 | | 35-45 | 5.1 | 146 | 1 | 14 | 10 | .04 |
| 6108 | | 40-50 | 5.4 | 413 | 2 | 18 | 60 | .14 |
| 6109 | | 50-60 | 5.7 | 455 | 2 | 17 | 155 | .34 |
| 6110 | | 60-70 | 6.0 | 510 | 2 | 16 | 160 | .37 |
| 6111 | | 70-80 | 6.6 | 590 | 2 | 14 | 350 | .62 |
| 6112 | | 90-95 | 7.0 | 525 | 1 | 11 | 380 | .75 |
| 6113 | 28 | 0-10 | 4.5 | 290 | 3 | 22 | 10 | .04 |
| 6114 | | 40-50 | 5.4 | 445 | 2 | 24 | 345 | .79 |
| 6115 | | 55-65 | 6.4 | 628 | 2 | 19 | 535 | .91 |
| 6116 | | 85-95 | 6.9 | 605 | 2 | 14 | 605 | 1.11 |
| 6117 | | 130-140 | 7.3 | 513 | 1 | 11 | 715 | 1.50 |
| 6118 | 29 | 0-10 | 6.0 | 648 | 4 | 78 | 875 | 1.44 |
| 6119 | | 30-40 | 6.6 | 810 | 2 | 29 | 20 | .03 |
| 6120 | | 40-45 | 7.2 | 740 | 2 | 24 | 10 | .02 |
| 6121 | 30 | 0-10 | 4.6 | 298 | 1 | 52 | 10 | .04 |
| 6122 | | 40-50 | 5.5 | 250 | 1 | 16 | 10 | .04 |

Appendix B (continued)

| Lab. No. | Site No. | Depth cm. | pH | Mg | P | K | Ca | Ca:Mg |
|---|---|---|---|---|---|---|---|---|
| | | | | ppm | | | | |
| 6123 | | 75-85 | 6.0 | 363 | 3 | 19 | 10 | .03 |
| 6124 | | 90-95 | 6.0 | 380 | 3 | 20 | 10 | .03 |
| 6125 | 31 | 0-10 | 4.7 | 215 | 2 | 47 | 10 | .06 |
| 6126 | | 10-20 | 5.2 | 45 | 2 | 19 | 10 | .22 |
| 6127 | | 20-40 | 5.1 | 35 | 1 | 20 | 10 | .42 |
| 6128 | 32 | 0-6 | 6.4 | 660 | 38 | 288 | 1800 | 2.82 |
| 6129 | | 20-30 | 7.2 | 618 | 8 | 409 | 380 | .63 |
| 6130 | | 60-70 | 7.3 | 598 | 3 | 330 | 15 | .03 |
| 6131 | | 80-90 | 7.2 | 695 | 3 | 255 | 15 | .02 |
| 6132 | 33 | 0-10 | 5.8 | 783 | 2 | 72 | 370 | .49 |
| 6133 | | 20-30 | 6.1 | 643 | 2 | 25 | 50 | .08 |
| 6134 | | 30-40 | 5.9 | 623 | 2 | 28 | 15 | .03 |
| 6135 | | 40-50 | 6.1 | 665 | 2 | 32 | 10 | .02 |
| 6136 | | 50-60 | 6.0 | 675 | 2 | 34 | 10 | .02 |
| 6137 | | 60-70 | 6.2 | 683 | 2 | 34 | 10 | .02 |
| 6138 | | 75-85 | 6.5 | 645 | 2 | 35 | 10 | .02 |
| 6139 | | 85-95 | 6.6 | 668 | 2 | 30 | 10 | .02 |
| 6140 | | 110-120 | 6.7 | 698 | 3 | 29 | 10 | .02 |
| 6141 | 34 | 0-10 | 6.2 | 533 | 2 | 34 | 535 | 1.08 |
| 6142 | | 50-60 | 5.7 | 630 | 2 | 34 | 190 | .33 |
| 6143 | | 100-110 | 6.6 | 795 | 17 | 38 | 225 | .31 |
| 6144 | | 165-175 | 6.8 | 675 | 3 | 29 | 220 | .35 |
| 6145 | 35 | 0-10 | 5.9 | 655 | 1 | 50 | 45 | .06 |
| 6146 | | 10-20 | 6.6 | 485 | 2 | 30 | 50 | .10 |
| 6147 | | 20-30 | 6.8 | 450 | 2 | 24 | 35 | .07 |
| 6148 | | 30-40 | 6.9 | 448 | 2 | 24 | 25 | .05 |
| 6149 | 36A | 0-3 | 3.9 | 100 | 3 | 60 | 10 | 1.03 |
| 6150 | | 3-20 | 4.5 | 8 | 6 | 35 | 10 | 5.34 |
| 6151 | | 20-25 | 4.6 | 9 | 2 | 30 | 11 | 2.84 |
| 6152 | 36B | 0-10 | 4.6 | 11 | 3 | 59 | 1 | 1.17 |
| 6153 | | 10-20 | 4.6 | 9 | 1 | 30 | 10 | 2.00 |

Appendix B (continued)

| Lab. No. | Site No. | Depth cm. | pH | Mg | P | K | Ca | Ca:Mg |
|---|---|---|---|---|---|---|---|---|
| | | | | ppm | | | | |
| 6154 | | 20-30 | 4.8 | 9 | 2 | 24 | 10 | 2.00 |
| 6155 | | 30-40 | 4.7 | 9 | 1 | 25 | 10 | 2.84 |
| 6156 | | 40-50 | 4.9 | 29 | 1 | 24 | 10 | .53 |
| 6157 | | 50-60 | 5.2 | 111 | 1 | 23 | 10 | .09 |
| 6158 | | 60-70 | 5.3 | 174 | 1 | 22 | 10 | .06 |
| 6159 | | 70-80 | 5.2 | 171 | 1 | 22 | 10 | .06 |
| 6160 | | 80-90 | 5.4 | 151 | 1 | 21 | 10 | .07 |
| 6161 | | 90-100 | 5.5 | 165 | 1 | 20 | 10 | .06 |
| 6162 | 37 | 0-10 | 5.9 | 443 | 1 | 29 | 250 | .56 |
| 6163 | | 30-40 | 5.8 | 538 | 1 | 34 | 25 | .05 |
| 6164 | | 45-50 | 6.4 | 970 | 2 | 35 | 20 | .02 |
| 6165 | | 55-65 | 6.9 | 1135 | 2 | 30 | 40 | .04 |
| 6166 | 38 | 0-10 | 4.6 | 575 | 1 | 26 | 10 | .02 |
| 6167 | | 25-35 | 6.4 | 505 | 2 | 32 | 15 | .03 |
| 6168 | | 45-55 | 6.6 | 530 | 2 | 40 | 25 | .05 |
| 6169 | 39 | 0-10 | 5.5 | 308 | 1 | 51 | 435 | 1.63 |
| 6170 | | 10-20 | 5.7 | 78 | 1 | 21 | 220 | 2.91 |
| 6171 | | 40-50 | 6.3 | 121 | 2 | 15 | 225 | 1.89 |
| 6172 | | 60-65 | 6.4 | 173 | 2 | 16 | 280 | 1.65 |
| 6173 | 40 | 0-10 | 4.8 | 151 | 1 | 32 | 15 | .12 |
| 6174 | | 10-20 | 5.4 | 353 | 1 | 15 | 20 | .06 |
| 6175 | | 40-50 | 5.9 | 475 | 1 | 27 | 55 | .12 |
| 6176 | | 90-95 | 5.6 | 450 | 2 | 24 | 55 | .12 |
| 6177 | 41A | 0-10 | 4.7 | 235 | 1 | 47 | 75 | .90 |
| 6178 | | 10-20 | 4.8 | 59 | 1 | 19 | 10 | .43 |
| 6179 | | 30-35 | 5.0 | 122 | 1 | 17 | 10 | .09 |
| 6180 | | 60-65 | 5.6 | 418 | 2 | 25 | 50 | .13 |
| 6181 | 41B | 0-10 | 5.4 | 380 | 1 | 35 | 100 | .27 |
| 6182 | | 30-35 | 5.2 | 280 | 1 | 18 | 15 | .06 |
| 6183 | | 45-55 | 5.6 | 310 | 1 | 21 | 95 | .31 |
| 6184 | | 85-90 | 5.8 | 338 | 2 | 21 | 235 | .71 |

Appendix B (continued)

| Lab. No. | Site No. | Depth cm. | pH | Mg | P | K | Ca | Ca:Mg |
|---|---|---|---|---|---|---|---|---|
| | | | | ppm | | | | |
| 6185 | 42 | (B3-C) | 6.6 | 498 | 2 | 12 | 255 | .51 |
| 6186 | 43 | 90-100 | 6.0 | 443 | 2 | 22 | 340 | .78 |
| 6187 | | 150-160 | 6.4 | 320 | 2 | 14 | 305 | 1.00 |
| 6188 | 44 | 0-10 | 5.7 | 363 | 1 | 24 | 15 | .04 |
| 6189 | | 40-50 | 7.0 | 490 | 2 | 26 | 15 | .03 |
| 6190 | | 60-70 | 7.0 | 540 | 2 | 28 | 15 | .03 |
| 6191 | | 130-135 | 7.0 | 608 | 2 | 21 | 15 | .03 |
| 6192 | 45 | 0-10 | 6.9 | 395 | 2 | 24 | 755 | 2.05 |
| 6193 | | 35-40 | 7.1 | 468 | 2 | 24 | 110 | .24 |
| 6194 | | 60-70 | 7.5 | 278 | 2 | 17 | 65 | .24 |
| 6195 | 46 | (B2) | 7.0 | 435 | 3 | 27 | 105 | .24 |
| 6196 | 47 | 0-10 | 4.5 | 137 | 1 | 15 | 10 | 1.27 |
| 6197 | | 30-35 | 4.6 | 51 | 1 | 15 | 10 | .26 |
| 6198 | | 40-45 | 5.4 | 275 | 1 | 16 | 15 | .06 |
| 6199 | | 50-60 | 5.5 | 415 | 2 | 24 | 60 | .14 |
| 6200 | 48A | 30-40 | 6.5 | 638 | 2 | 29 | 235 | .37 |
| 6201 | 48B | 10-20 | 6.3 | 578 | 2 | 27 | 155 | .28 |

Appendix C. Elemental analyses of coarse and fine silt fractions from the seven profiles studied

| Lab No. | Depth cm. | Coarse Silt CaO | Coarse Silt $K_2O$ | Coarse Silt $Fe_2O_3$ | Coarse Silt $TiO_2$ | Coarse Silt $ZrO_2$ | Fine Silt CaO | Fine Silt $K_2O$ | Fine Silt $Fe_2O_3$ | Fine Silt $TiO_2$ | Fine Silt $ZrO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | | | | % | | | | |
| 6202 | 0-6 | 1.75 | 1.39 | 1.85 | 1.22 | 0.087 | 0.62 | 1.94 | 2.48 | 1.29 | 0.036 |
| 6203 | 6-21 | 1.78 | 1.34 | 1.66 | 1.25 | 0.100 | 0.64 | 1.98 | 2.34 | 1.33 | 0.045 |
| 6204 | 21-26 | 1.32 | 1.21 | 1.71 | 1.21 | 0.103 | 0.60 | 2.14 | 2.56 | 1.38 | 0.042 |
| 6205 | 26-32 | 1.38 | 2.09 | 3.07 | 1.30 | 0.081 | 0.57 | 2.55 | 4.24 | 1.19 | 0.027 |
| 6206 | 32-38 | 1.68 | 2.03 | 3.42 | 1.28 | 0.075 | 0.75 | 2.46 | 4.65 | 1.13 | 0.024 |
| 6207 | 38-60(si) | 2.60 | 1.63 | 2.50 | 1.04 | 0.054 | 1.19 | 1.46 | 4.06 | 1.05 | 0.023 |
| 6210 | 0-11 | 1.27 | 1.56 | 2.49 | 1.34 | 0.085 | 0.88 | 1.67 | 3.44 | 1.38 | 0.036 |
| 6211 | 11-18 | 1.25 | 1.68 | 2.67 | 1.41 | 0.095 | 0.82 | 1.71 | 4.03 | 1.31 | 0.029 |
| 6212 | 18-29 | 1.65 | 1.66 | 3.44 | 1.24 | 0.078 | 0.95 | 1.84 | 6.32 | 1.19 | 0.033 |
| 6213 | 29-45 | 3.67 | 1.52 | 5.38 | 1.20 | 0.047 | 1.49 | 1.43 | 9.82 | 1.03 | 0.012 |
| 6214 | 45-54 | 4.81 | 1.51 | 6.32 | 0.94 | 0.022 | 1.85 | 1.15 | 12.25 | 0.98 | 0 |
| 6215 | 54-75 | 4.14 | 1.52 | 6.09 | 0.95 | 0.036 | 1.76 | 1.22 | 10.75 | 0.98 | 0 |
| 6216 | 75-92 | 7.13 | 0.98 | 7.78 | 0.77 | 0.001 | 3.18 | 0.87 | 12.30 | 0.80 | 0 |
| 6217 | 92-110 | 9.80 | 0.70 | 6.42 | 0.59 | 0 | 4.87 | 0.67 | 11.16 | 0.61 | 0 |
| 6218 | 110-138 | 6.27 | 0.46 | 12.38 | 0.73 | 0 | 2.44 | 0.36 | 18.88 | 0.74 | 0.010 |
| 6219 | 138-154 | 7.18 | 0.45 | 11.78 | 0.79 | 0 | 2.87 | 0.35 | 19.14 | 0.78 | 0 |
| 6220 | 0-4 | 0.58 | 1.30 | 1.88 | 0.98 | 0.081 | 0.56 | 1.87 | 2.71 | 1.14 | 0.032 |
| 6221 | 4-16 | 0.54 | 1.41 | 1.47 | 1.07 | 0.097 | 0.42 | 1.88 | 2.11 | 1.20 | 0.039 |
| 6222 | 16-28 | 0.61 | 1.80 | 2.04 | 1.04 | 0.103 | 0.40 | 2.29 | 3.14 | 1.07 | 0.038 |
| 6223 | 28-40 | 0.72 | 2.06 | 3.52 | 1.07 | 0.081 | 0.43 | 2.37 | 5.44 | 0.97 | 0.021 |
| 6224 | 40-53 | 0.77 | 1.87 | 5.30 | 0.94 | 0.062 | 0.45 | 2.02 | 7.56 | 0.84 | 0.012 |
| 6225 | 53-75 | 0.40 | 1.14 | 15.99 | 0.56 | 0.009 | 0.31 | 1.51 | 12.59 | 0.61 | 0 |
| 6226 | 75-91 | 0.05 | 0.26 | 20.61 | 0.20 | 0 | 0.13 | 0.68 | 17.64 | 0.27 | 0 |
| 6227 | 91-107 | 0.09 | 0.25 | 28.47 | 0.14 | 0 | 0.07 | 0.45 | 21.33 | 0.18 | 0 |
| 6228 | 107-123 | 0.08 | 0.11 | 28.11 | 0.05 | 0 | 0.05 | 0.21 | 22.82 | 0.07 | 0 |
| 6229 | 123-139 | 0.05 | 0.07 | 17.80 | 0.03 | 0 | 0.02 | 0.12 | 18.29 | 0.04 | 0 |
| 6230 | 139-155 | 0.05 | 0.07 | 28.76 | 0.03 | 0 | 0.03 | 0.09 | 18.16 | 0.03 | 0 |
| 6231 | 155-170 | 0.06 | 0.10 | 25.60 | 0.04 | 0 | 0.04 | 0.13 | 16.55 | 0.05 | 0 |

Appendix C (continued)

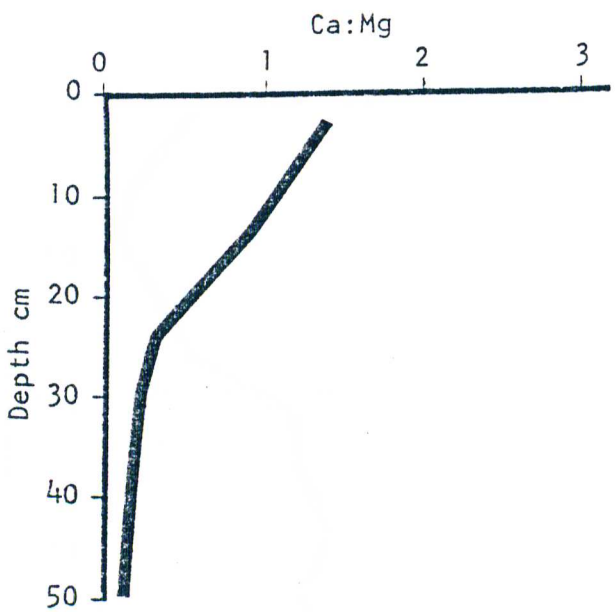
| Lab No. | Depth cm. | Coarse Silt | | | | | Fine Silt | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CaO | $K_2O$ | $Fe_2O_3$ | $TiO_2$ | $ZrO_2$ | CaO | $K_2O$ | $Fe_2O_3$ | $TiO_2$ | $ZrO_2$ |
| | | % | | | | | | | | | |
| 6232 | 0-2 | 0.56 | 1.52 | 1.45 | 1.01 | 0.094 | 0.45 | 1.45 | 2.18 | 1.12 | 0.042 |
| 6233 | 2-8 | 0.59 | 1.63 | 1.35 | 1.19 | 0.104 | 0.45 | 1.99 | 2.19 | 1.26 | 0.045 |
| 6234 | 2-18 | 0.59 | 1.55 | 1.58 | 1.18 | 0.100 | 0.43 | 2.01 | 2.46 | 1.20 | 0.041 |
| 6235 | 18-26 | 0.57 | 1.88 | 3.13 | 1.01 | 0.061 | 0.36 | 2.10 | 4.03 | 0.94 | 0.017 |
| 6236 | 26-43 | 0.72 | 2.10 | 3.86 | 1.09 | 0.067 | 0.48 | 2.38 | 4.99 | 0.89 | 0.010 |
| 6237 | 41-43 | 0.77 | 1.95 | 5.11 | 1.01 | 0.052 | 0.45 | 2.01 | 5.54 | 0.78 | 0.008 |
| 6238 | 0-6 | 2.82 | 1.13 | 1.97 | 1.28 | 0.116 | 1.17 | 1.51 | 2.16 | 1.38 | 0.044 |
| 6239 | 6-16 | 2.81 | 1.21 | 2.02 | 1.18 | 0.106 | 1.20 | 1.49 | 2.38 | 1.34 | 0.038 |
| 6240 | 16-32 | 2.18 | 1.57 | 2.13 | 1.22 | 0.118 | 0.81 | 2.07 | 3.38 | 1.32 | 0.033 |
| 6241 | 32-55 | 0.98 | 2.15 | 2.38 | 1.25 | 0.106 | 0.54 | 2.15 | 5.74 | 1.26 | 0.021 |
| 6242 | 55-75 | 1.12 | 2.23 | 2.15 | 1.34 | 0.115 | 0.65 | 2.40 | 4.74 | 1.21 | 0.023 |
| 6243 | 75-95 | 1.97 | 2.12 | 2.85 | 1.11 | 0.087 | 0.99 | 2.32 | 5.66 | 1.20 | 0.016 |
| 6244 | 95-110 | 10.54 | 0.10 | 6.67 | 0.11 | 0 | 6.85 | 0.16 | 12.26 | 0.19 | 0 |
| 6245 | 110-130 | 11.05 | 0.07 | 6.82 | 0.08 | 0 | 6.38 | 0.13 | 12.61 | 0.12 | 0 |
| 6246 | 130-155 | 9.06 | 0.05 | 8.33 | 0.07 | 0 | 4.98 | 0.13 | 13.67 | 0.10 | 0 |
| 6247 | 155-175 | 10.54 | 0.06 | 7.42 | 0.06 | 0 | 6.87 | 0.15 | 10.97 | 0.09 | 0 |
| 6248 | 175-205 | 10.90 | 0.06 | 7.70 | 0.08 | 0 | 6.94 | 0.14 | 13.15 | 0.12 | 0 |
| 6249 | 0-18 | 1.21 | 1.03 | 1.39 | 1.14 | 0.124 | 0.54 | 1.70 | 2.22 | 1.40 | 0.049 |
| 6250 | 18-55 | 0.23 | 1.15 | 4.41 | 1.17 | 0.088 | 0.18 | 1.36 | 7.22 | 1.13 | 0.014 |
| 6251 | 55-78 | 0.16 | 0.40 | 16.48 | 1.04 | 0.021 | 0.14 | 0.54 | 14.14 | 0.91 | 0 |
| 6252 | 78-103 | 0.90 | 0.27 | 23.10 | 0.69 | 0 | 0.36 | 0.31 | 17.35 | 0.58 | 0 |
| 6253 | 103-130 | 4.53 | 0.11 | 11.45 | 0.34 | 0 | 0.99 | 0.16 | 15.41 | 0.37 | 0 |
| 6254 | 130-158 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 6255 | 158-183 | 6.23 | 0.21 | 11.89 | 0.16 | 0 | 1.58 | 0.24 | 14.94 | 0.20 | 0 |
| 6256 | 183-211 | 7.33 | 0.46 | 9.28 | 0.15 | 0 | 2.46 | 0.41 | 12.70 | 0.20 | 0 |
| 6257 | 211-236 | 9.31 | 0.39 | 7.93 | 0.11 | 0 | 3.06 | 0.38 | 12.60 | 0.18 | 0 |
| 6258 | 236-260 | 8.93 | 0.19 | 8.83 | 0.13 | 0 | 3.20 | 0.22 | 14.34 | 0.20 | 0 |
| 6259 | 260-285 | 2.40 | 0.10 | 5.07 | 0.18 | 0.031 | 1.18 | 0.14 | 7.05 | 0.20 | 0.003 |

Appendix C (continued)

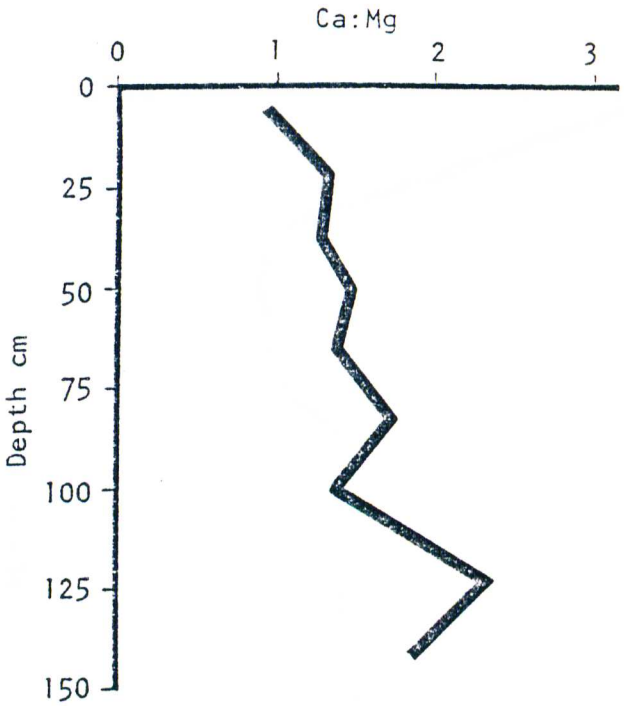
| Lab No. | Depth cm. | Coarse Silt | | | | | Fine Silt | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CaO | $K_2O$ | $Fe_2O_3$ | $TiO_2$ | $ZrO_2$ | CaO | $K_2O$ | $Fe_2O_3$ | $TiO_2$ | $ZrO_2$ |
| | | % | | | | | | | | | |
| 6260 | 285-310 | 1.94 | 0.10 | 5.88 | 0.23 | 0.027 | 1.14 | 0.16 | 7.47 | 0.23 | 0.009 |
| 6261 | 310-346 | 1.74 | 0.10 | 8.30 | 0.33 | 0.011 | 1.15 | 0.14 | 10.23 | 0.32 | 0 |
| 6262 | 346-371 | 2.02 | 0.14 | 7.29 | 0.25 | 0.020 | 1.35 | 0.20 | 9.37 | 0.29 | 0 |
| 6263 | 371-383 | 2.58 | 0.30 | 13.67 | 0.33 | 0 | 1.46 | 0.48 | 15.65 | 0.33 | 0 |
| 6264 | 383-400 | 3.87 | 0.28 | 14.94 | 0.60 | 0 | 1.83 | 0.34 | 17.40 | 0.59 | 0 |
| 6265 | 400-430 | 4.64 | 0.19 | 14.30 | 0.64 | 0 | 1.73 | 0.22 | 16.64 | 0.63 | 0 |
| 6266 | 0-3 | 0.46 | 1.12 | 1.76 | 0.98 | 0.109 | 0.40 | 1.55 | 2.89 | 1.18 | 0.038 |
| 6267 | 3-27 | 0.50 | 1.33 | 2.16 | 1.03 | 0.096 | 0.36 | 1.72 | 3.48 | 1.09 | 0.024 |
| 6268 | 27-43 | 0.63 | 1.63 | 3.88 | 0.99 | 0.077 | 0.44 | 1.94 | 6.12 | 0.95 | 0.014 |
| 6269 | 43-70 | 0.82 | 1.86 | 3.59 | 1.07 | 0.084 | 0.52 | 2.41 | 5.88 | 0.95 | 0.015 |
| 6270 | 70-92 | 0.88 | 1.81 | 2.96 | 1.08 | 0.094 | 0.68 | 2.70 | 5.71 | 1.02 | 0.015 |
| 6271 | 92-100 | 0.77 | 1.23 | 5.83 | 0.79 | 0.052 | 0.52 | 1.60 | 7.63 | 0.67 | 0.003 |
| 6272 | 100-104 | 0.60 | 0.65 | 8.47 | 0.37 | 0.014 | 0.35 | 0.89 | 8.28 | 0.34 | 0 |

Appendix D. Extractable Ca:Mg ratios with depth in the seven profiles studied.

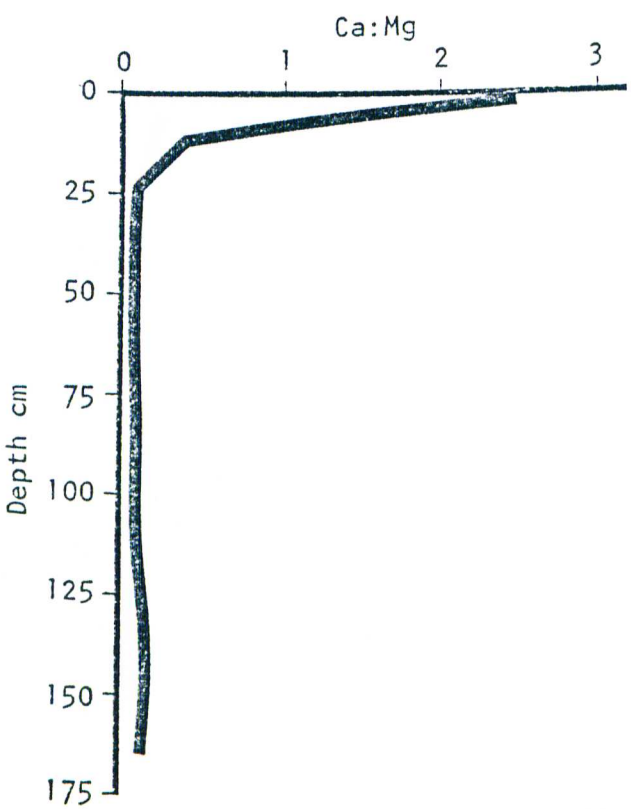
Profile 1



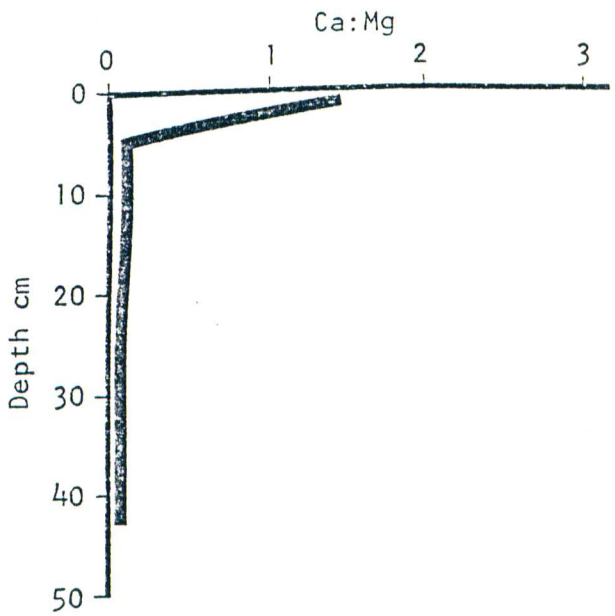

Profile 2




Profile 3

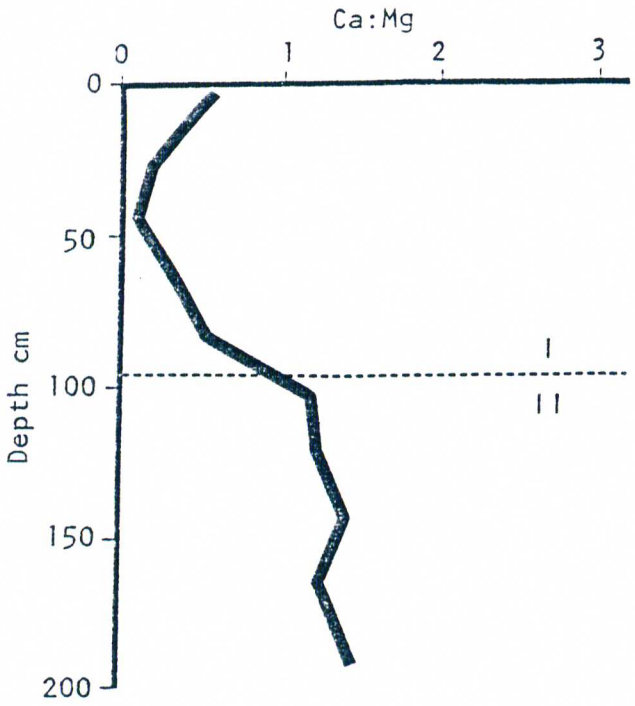



Profile 4

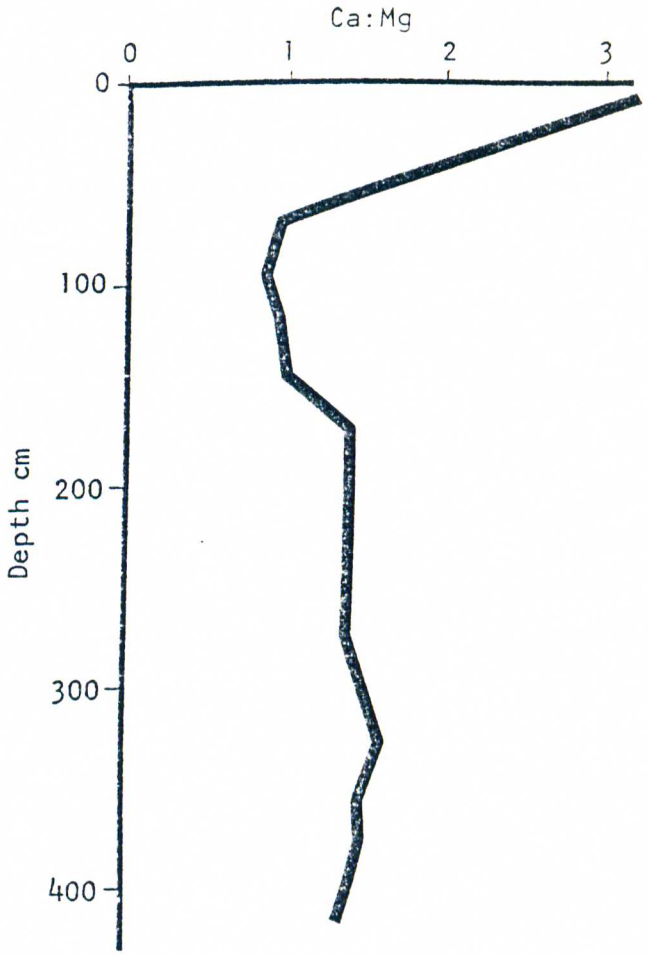


Appendix D (continued)

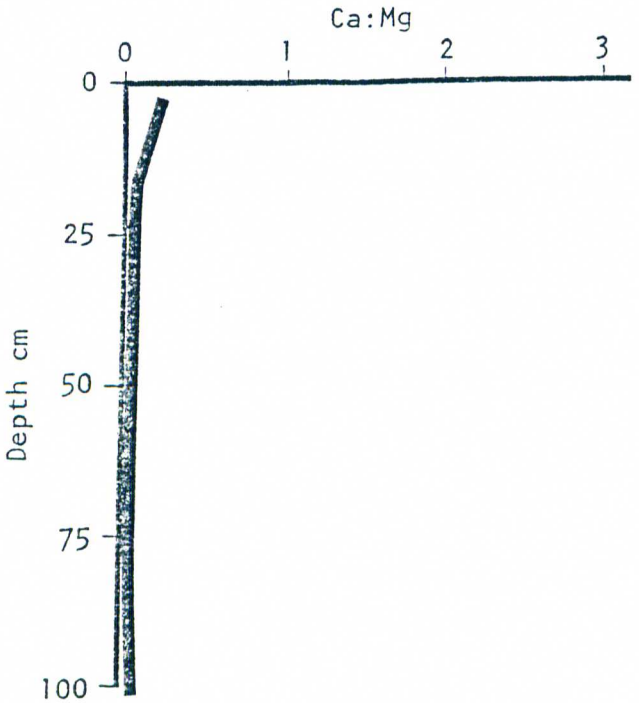
Profile 5




Profile 6




Profile 7



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2. Rabenhorst, M. C., and J. E. Foss. 1977. Chemical and mineralogical examination of serpentine and associated soils in Maryland. Crops and Soils Research 1976. Maryland Agri. Exp. Station. Progress Research Report Vol. 10: 226-230.

3. Foss, J. E., W. R. Wright, D. P. Wagner, D. S. Fanning, and M. C. Rabenhorst. 1978. Paleosols and relict soils in coastal plain sediments of Maryland. Int. Congr. Soil Sci. Abstracts, 11th (Edmonton, Canada) I: 221.

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